

# ***DOTTED LANDSCAPE***

*Constructive research into interactive displays in shared spaces*

Media Lab Master Thesis 2012  
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**ABSTRACT**

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<i>Title</i> Dotted Landscape		
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<i>Abstract</i> <p>Our urban visual world is overflowed with messages mostly coming from advertisers and public officials. The information is pushed to our consciousness without giving us a chance to reply. No real dialogue takes place. I would like to see a change in this and bring more possibilities for interaction into our shared and public spaces.</p> <p>In my thesis I review the research on public display design and map the context by looking at the history of public space. Design models and methods are introduced to overcome the shortcomings of traditional human-computer interaction design. However, the focus of the work is on a production: the Dotted Landscape light panel that allows remote controlling through a web user interface. By opening the web site users can draw collaboratively, create animations and write text messages that are displayed real-time on the light panel.</p> <p>Form and interface design is described in one main chapter and the software and electronics in another. In addition to the description of the current system, both chapters include future plans influenced by user testing sessions. The description of these sessions along with analysis of the results is included in another chapter. Finally a conclusion of the production and research work is provided.</p>		
<i>Keywords</i> interactive displays, public space, web applications, electronics, production		

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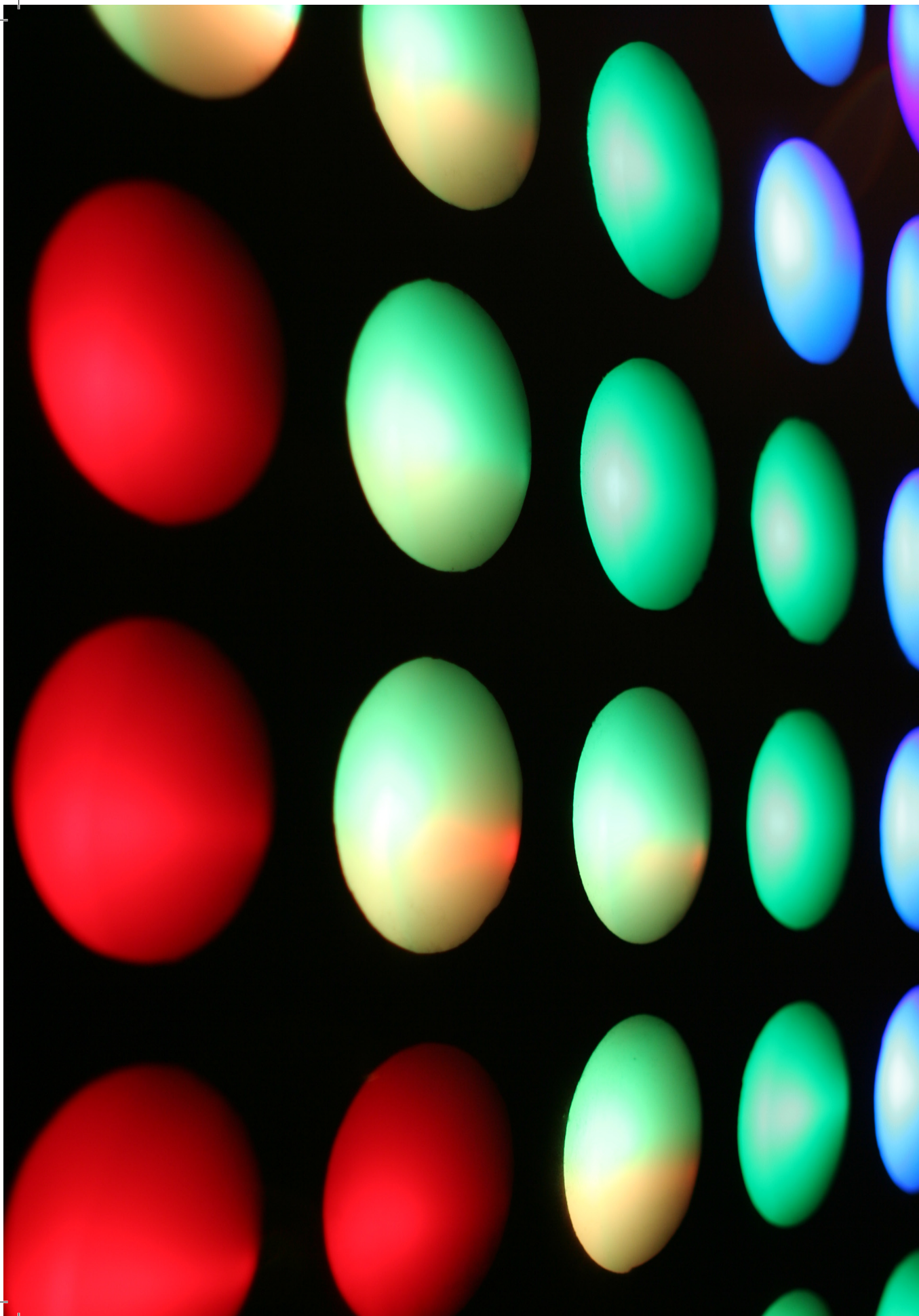
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## 0 Introduction

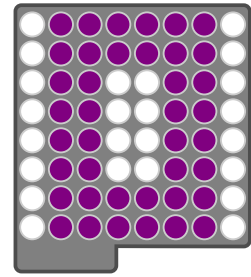
We are all accustomed to being bombarded by visual messages during our daily lives. While walking in any modern town, a variety of advertisements and information displays constantly fight for our attention. Most of these are automatically filtered out by our visual system and the few that make it to our consciousness are rarely important to us. The focus here is on information push. We are the consumers of messages provided to us by media, advertisers and public officials. Instead of this one-way communication I would rather see a dialogue and along with others (Struppek 2006, Eriksson et al. 2007, Viña 2010) I want to pose the question: is this the only type of information exchange possible in public places?

The amount and pervasiveness of technology in our cities is growing: more and more surveillance cameras are being installed, wireless networks are available everywhere and the amount of portable devices grows constantly. However, this increase in technology is not aimed to bring us together, but rather to keep us safe from each other. Our mobile phones don't link us to our surroundings but disconnect us from them, while our public spaces are becoming more controlled, formalized and built for a certain purpose.

Virtually everyone in a modern city is carrying a mobile device with them. A large portion of these devices are connected to the web and becoming increasingly more powerful tools of expression. Although mobile devices help us connect to people we know, they rarely help us approach the people we see around us. On the contrary, researchers such as Eriksson et al. (2007) would argue that our mobile phones and other devices are designed for a single-user experience and create personal spheres inside our public areas further challenging the interaction with strangers. This means that our immersive mobile technologies – while claiming to connect us – are actually transferring us out of the physical location, to communicate within our closed circles through mediums such as Facebook and instant messaging.

I'm interested in bringing more interaction channels and possibilities for creativity to the public sphere. This is not a value proposition – images created by advertising professionals are in many cases visually more appealing than those drawn by random passersby. I'm not aiming for a better world, just a slightly different one. I want to raise questions about the role our public locations play in our lives and who in the end should be controlling their evolution. Like Eriksson and her group, I would want to see a change from “information push towards information dialogue”.

In this thesis I focus on the challenge of designing an interactive display surface for a shared space or public location. The end result is Dotted Landscape – a 1 meter times 1 meter light panel with rounded

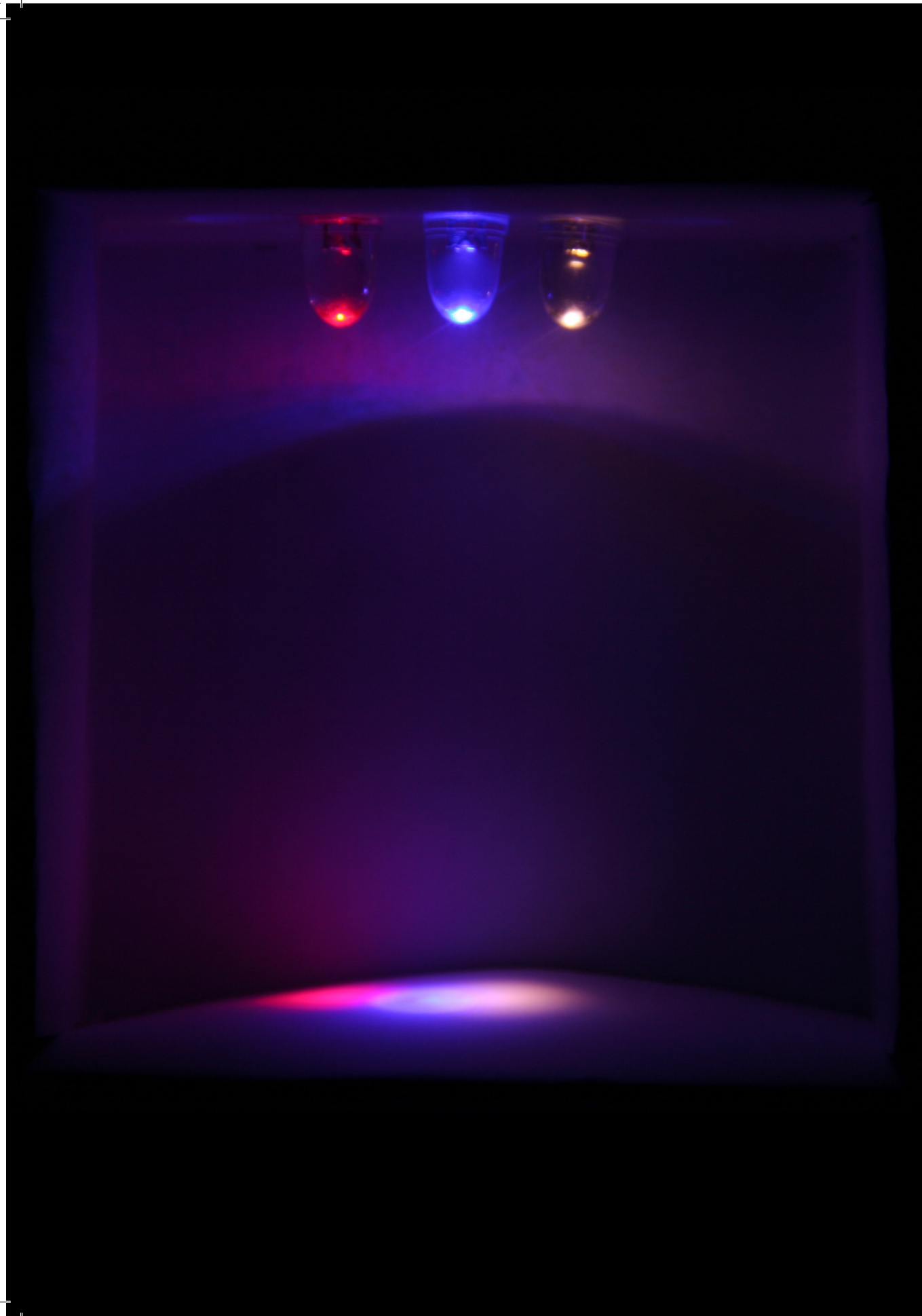


wood veneer edges and a misty acrylic front. The light panel runs its own web server that allows creation of animations, writing of text messages and free drawing on top of the panel using any modern web browser. This means people with smart phones, tablets, laptops or any computer equipped with a web browser can directly interact with the light panel without installing any extra software. Users can also play animations made by others and discuss the service through the touch-driven user interface.

This written portion is divided into two: a look into the challenges and context of designing interactive displays for shared spaces, and a description of the Dotted Landscape production. Starting with the history and context of public space I will move into display technology and the challenges introduced by interactivity. After that I will continue to the user interface, software and hardware design of Dotted Landscape and lastly to the results of user testing.









# 1 The context of public display design

The concept of a public space is an amazing centuries old creation that exists in all cultures around the world. It provides an interface between different classes, races and nationalities. While this no-man's land provides wide possibilities for meaningful interaction and enrichment of social life, it also creates conflict and chaos. Jurisdiction is widely applied upon the contemporary public location. For example freedoms regarding speech and public gathering have been greatly limited in the name of safety. Many previously public activities have also been banned or moved to the private sphere to evade the need for society to control them. A notable example of this is alcohol consumption, which in many western countries has lately been criminalized in urban public locations.

Successful design for public locations relies on first understanding the context. By looking at the historical perspective of public life and seeing what our current status is, I hope to deepen my understanding of the underlying problems and design challenges. After reviewing the history of public space, I will move to public display technology and how it can be viewed in architecture.

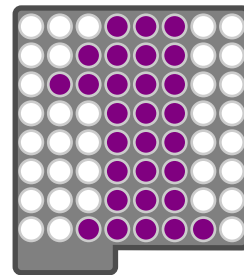
## 1.0 History of public squares

The phrase “public place” is often synonymous with the marketplace or central square of a city. Even though in the broader sense “public space” covers most shared places of our planet from streets to parks to wildlife preservations, looking at the development of the central element in public life – the square – we can see how society's view has changed over the centuries.

Western examples on public space usually start with a mention of the Greek *agorae* – an open location in the middle of larger towns in ancient Greece. The Agora acted as a hub for trade and commerce much like a modern marketplace, but in addition it had a political role as the staging place of debates and discussions. This brought the use of power to the public and can be seen as one of the examples of early democratic process.

Following the Greeks, the Romans also designed their cities around a central public location called the *forum*. The political system in ancient Rome was centralized and hierarchical, and therefore the forum did not act as a hub of political power, but still provided the crucial location for commerce and social interaction.

Public squares built during the middle ages often display a lack of symmetry. The streets and forms of buildings during that time cre-



ated a sensation of an organic city. This was mostly due to the builders who would rather follow the contours of nature than symmetry. Central squares played a major role as the main hub for commerce.

Calculated art and correct perspective were sought during the Renaissance period. This also meant that city planning became the norm rather than the exception and public squares became symmetrical instead of organic in shape. Political power returned to city planning, but in a different light than in ancient Greece. The ruling class spent vast resources to build extensive palaces, boulevards and open squares to display their power to the people. Ironically these displays of power also acted as the starting points for revolutions, such as the *Place de la Concorde* in Paris, or the Senate Square of St. Petersburg.

The beginning of the twentieth century increased the use of public squares in politics. Especially totalitarian regimes built vast open spaces to display military power. Examples of such squares include the *Piazza Venezia* in Rome and the *Piazza San Babila* in Milan built by the Duce to accommodate his fascist rallies. The most prominent example comes from China where Mao Zedong extended the Tiananmen Square to a size where it would fit ninety-four football fields.

The decline of public space as a location for social gathering began already before the dictators. Starting from the nineteenth century the space was used more and more for parking. The automotive industry in the 1960's further continued this decline as cars became common and people started preferring the suburban lifestyle. The damage was further increased by city planners, such as the architect Le Corbusier, who favored cars above people in his designs. (Urban Space Initiative 2011)

Contemporary public squares still occupy a role as a place of celebration and demonstration. Global news agencies transmitted hours of footage during the Arab Spring as demonstrators took to the streets and squares in countries such as Tunisia, Yemen, Egypt and Algeria. Occupying the central squares of cities has always been one of the first signs of revolution. Another example partly inspired by Arab Spring was the Occupy Wall Street movement in New York, which used Zuccotti Park as their camping site. In this case the park was privately owned – a fact that contributed to the judge's decision to later ban the camping (The New York Times 2011, OccupyWallStreet 2011).

### *1.1 The demise of modern public space*

It is somewhat ironic that the history of the public square started with dialogue – the ancient *agorae* was a place of discussion and debate – and ended up here, where we are again faced with information push

(Eriksson et al. 2007, Vinã 2010) instead of two-way communication.

Suburbanization has been seen as one of the contributing factors to the demise of the public space as electronic media such as TV and radio took over roles which were previously handled in public locations. Events that were experienced communally in the public could now be followed from the comfort of one's home (McQuire 2006).

Today new technology is enabling the consumption of digital media in the public. With more powerful mobile devices, ubiquitous data networks and urban screens, the possibility to consume digital content anywhere we wish is better than ever before. Within this development, the screen technology is especially interesting due to the collective form of engagement introduced by the devices (McQuire 2006).

Some others alarmingly note that there seems to be a tendency to move public actions into private ones. Harrison and Dourish (1996) use the example of bedroom activities, which were until the medieval times an open activity, have now turned into private and concealed. According to Eriksson et al. (2007) the larger change can also be seen in the relationship of public-private. For example the consuming of alcoholic beverages has been made illegal in several countries despite it being perfectly acceptable on the terraces of surrounding cafés and bars. This in the end is the same social activity but potentially less controlled on the public side.

The current trend of development is not limited to law making as large parts of our public spaces are transformed into private space through the form of a mall or a shopping center. These locations are not only structured to control the use of the space but also limit the expression of opinions and filter out the people allowed to enter (Eriksson et al. 2007). In many cases it seems that the fear mentality from the beginning of the 21st century is making us take overly drastic measures to control our public sphere. Public space is less controlled, chaotic, unsafe and unpredictable than private, but we should still strike a balance between the freedom of expression and privatization of space. Is the public space in our cities slowly becoming a luxury?

These larger social movements should be considered by the designer of public displays. What kind of channels does the technology provide for the public and how do they mix with the surrounding environment. Does the technology increase the amount of communication between people in the space or does it allow them to avoid social discourse. Does the technology provide only curated content or does it support free speech? And in the end who carries the responsibility of misuse? A model that might make this classification easier is presented in Chapter 2



## 1.2 Development of public displays

Electrification in the 1920s brought large light displays into urban environments. These static light billboards were later accompanied by more general displays that could vary their content by controlling which lights were turned on. Historically these screens have been mostly used as relays for live events and platforms for information and advertising. An alternative context is provided by artists such as Jenny Holzer, who since the mid-80s has used information displays to transmit more controversial messages to the public (McQuire 2006).



**Image1: Jenny Holzer's For August, 2007. © Jenny Holzer, member Artists Rights Society (ARS), NY. Photo: Attilio Maranzan**

Today public displays and adverts are present in every modern city. Interestingly, São Paulo provides an exception. In a fairly bold move the city banned the use of outdoor advertising and pamphleteering in the public. The move to a logo-free city has been quite successful as 70 percent of the city's populace is supporting the change (Harris 2007). It is however questionable if such a drastic ban is the right way to go. Maybe there could be a golden path in the middle. Public displays are here to stay in one way or another. The question is how should we relate to them.

The field of architecture provides some interesting views on public displays. The view of Lev Manovich (2006) is that the current visual tradition of digital screens in our public space is a regression. The well-defined frame of a digital display follows the tradition of Alberti's window – the 15th century definition of pictorial representation – and through that also the post-Renaissance painting, cinema screen, TV and computer monitor. According to Manovich the visual language has transformed from a 3D virtual world of a Renaissance painting into a shallow combination of live-action footage, 2D and 3D elements, typography and scrolling data.

A similar viewpoint is shared by Parkes and Ängeslevä (2007) who feel that the current use of digital displays clashes with our existing architecture and the cultural characteristics of our environment. Their approach in bringing interactive content into the public space relies on using more innovative technologies such as thermochromic pigment that turns from transparent to black when heated. Using this ink technology they have transformed items such as clothes on a clothesline and the windows of a greenhouse into art pieces that come to life and more importantly, blend into their surroundings.

Robert Venturi's view on electronic displays is more positive. According to him the electronic display is not only a part of our architecture, but a very central piece of it – it is the defining characteristic of architecture in the information age. Since 1960s Venturi has argued that architecture should learn from the commercial culture of cities like Las Vegas and their modern phenomena such as billboards and strip malls. His vision of a modern city is one filled with complexity, contradiction and heterogeneity, not one of minimalism (Manovich 2006). His view on the importance of screens is partly shared by McQuire who notes them to be the most visible part of modern urbanism (McQuire 2006).

Architect Paul Virillio pointed out that there is a precedent to the information push that we are now seeing in our public spaces (Struppek 2006). He calls the modern high-rise buildings covered with screens as "Electronic Gothic", referring to the Gothic churches where the windows were aimed at affecting people's moral behavior. Robert Venturi takes the comparison a notch further and says that traditional architecture has always included ornamental iconography and that our current electronic displays are merely a logical continuation of the tradition. In his view we should embrace the use of electronic images and that architecture should return to its old definition as information surface.

As Manovich (2006) points out, this kind of transition back to architecture as information surface is not entirely unproblematic. In architecture the messages conveyed by structures are not limited to the flat outside surfaces but also extend to the spatial dimensions and forms

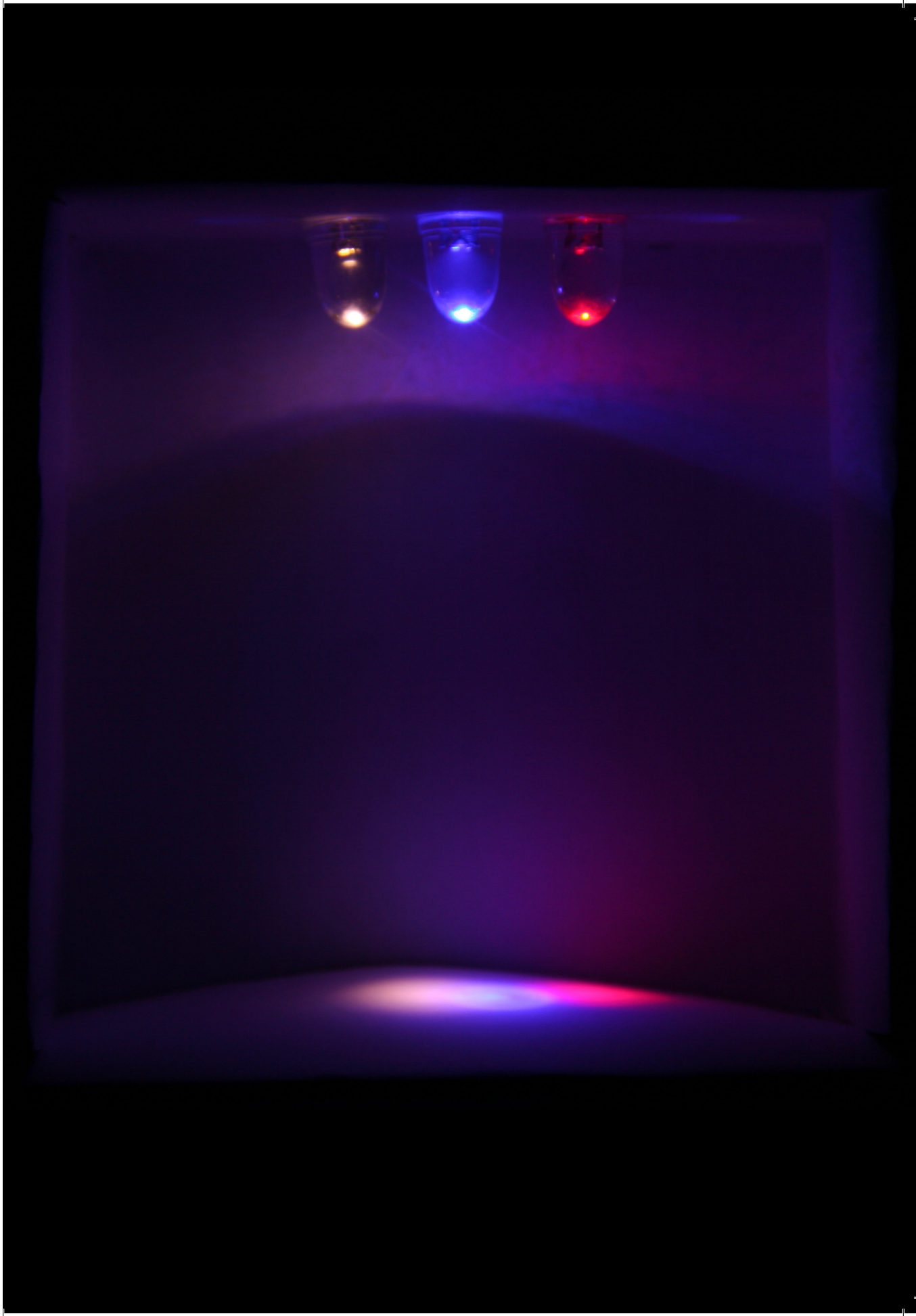
of the building. A medieval church not only used its icons and images, but also its high rising hallways and towers to convey its message of faith. Manovich continues to build the meaning of the architectural change we are now seeing in the information age by extending it from mere display technology to the enabling feature of computer systems and electronics to create the possibility of variability in otherwise static structures. With this technology lighting, displays, windows, doors, fountains and even walls of buildings can be controlled and mutated continuously. Following this notion Manovich suggests that modern architects take this variability and use it as a substance in their work rather than a void: the electronic content also needs “structure, a politics and a poetics”.

While I somewhat share Robert Venturi’s refusal of forced minimalism in our public space, I’m also worried about the politics and power settings behind our environment. Many of the display-filled locations these days are privately owned and as argued previously this tendency of privatization might continue further in the future. The question then is who controls what we see when we move around our living environment. Struppek (2006) also shares this concern of our “screen world” by asking the question “how can the use of these screens controlled by market forces be broadened and culturally curated?”. While many initiatives are already attacking this problem more cooperation is required to make sure that our shared visual environments don’t become overpolluted or simple one-way billboards for mass consumerism.

For the display designer the views shared here create a few interesting questions. First the form of the display should be well thought of. While the technology is much easier to use, a standard screen as the output mechanism might mean that the whole production blends into the urban environment and goes unseen. A review of possible alternatives for expression should be considered. Secondly the mix with existing architecture is worth noting. Is the piece intended as a physical intervention, such as Viña’s *Animato* project (2010) where the key objects were placed intentionally in the way of people, or as a blending element like the *Algorithmic Topiary* or *Thermochromic Laundry Line* by Parkes and Ängeslevä (2007) where thermographic ink was used on clothes and regular windows to allow the visual elements to blend into the existing structures. As the technology now allows for a very broad range of expression, it is up to the designer to decide which approach best suits him best.

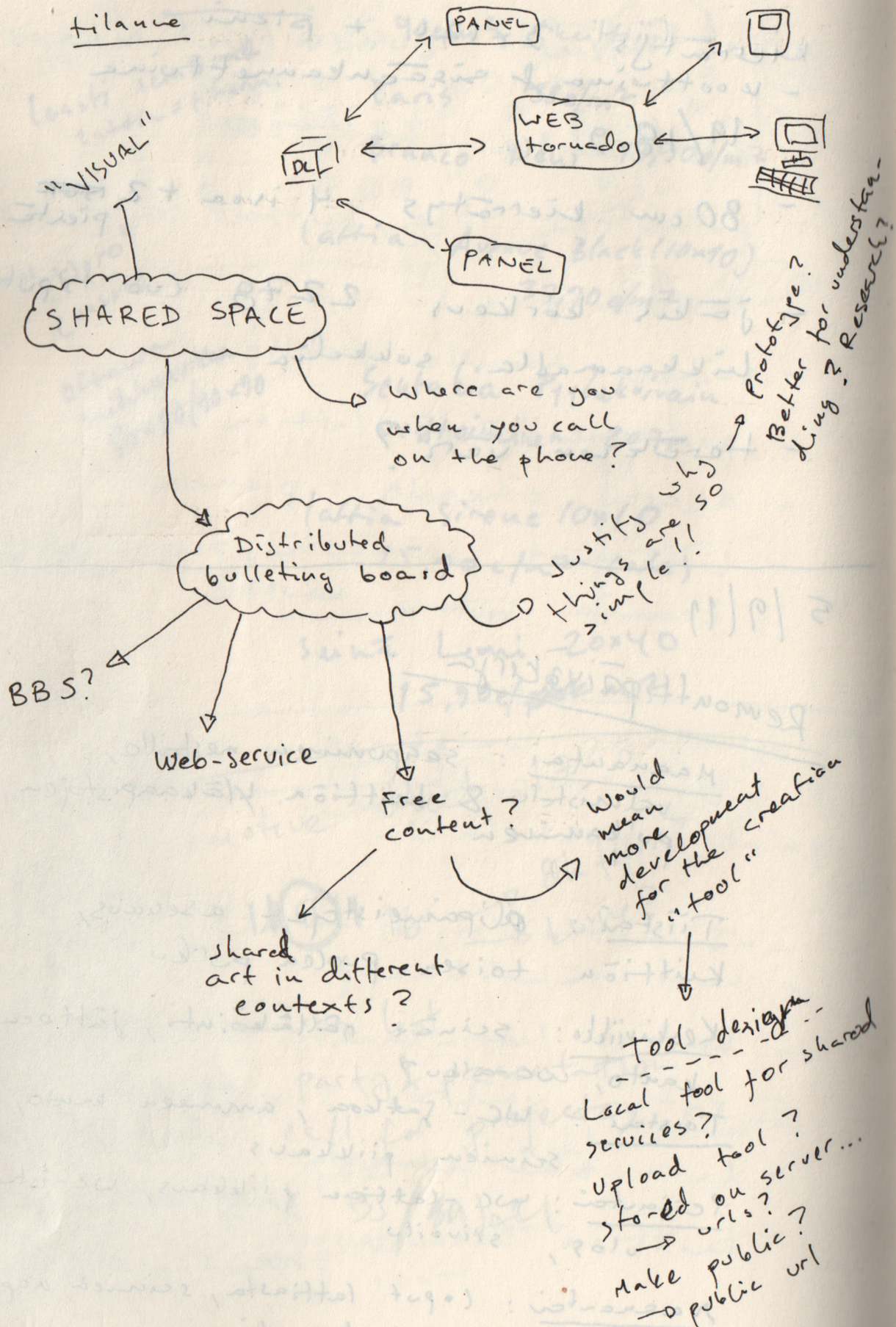
In addition to these viewpoints, the modern designer must also consider the introduction of interactivity and the additional challenges and possibilities it brings. As Manovich encourages the architects to embrace the variability granted by modern technology, so should digital designers prepare themselves to make use of new types of interactivity. This is the topic for the following Chapter.





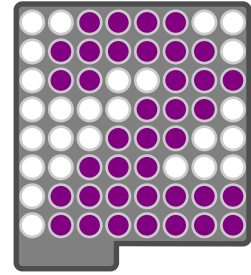


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## ***2 Interactive displays and the concept design of Dotted Landscape***



The recent big change to public display technology has been the introduction of interactivity. This brings new challenges to the design. Already getting a passerby to notice the display can be difficult in our visually overloaded urban environments. The lessons from the field of Human-Computer interaction (HCI) can't all be directly applied here – new lessons need to be learned.

To better understand the challenges and possibilities introduced by interactivity I first explain the concept of Dotted Landscape and then discuss a few frameworks for dissecting the interactive public display design field and what effect knowing these frameworks had on the design of Dotted Landscape. I conclude the Chapter by reviewing some related and inspiring works.

### ***2.0 Introduction to Dotted Landscape***

The initial inspiration for a light panel came in 2009. I have always been fascinated by interactive visual works that invite people to participate. My first inspiration for this line of art came from Graffiti Research Labs<sup>1</sup> and their Laser Tag -project – a huge live visual performance that allowed any passerby to write and draw on building facades. Another inspiration – the Blinkenlights<sup>2</sup> project – transforms entire building facades into interactive light panels by combining computers and electronics to trigger powerful lights inside the rooms. However I didn't want to create a spectacle or a performance – rather I would focus on something that blends into a space, slowly becoming part of it. Much like a nice piece of furniture.

As interaction was a central theme I started looking at different possibilities provided by contemporary public displays. It became evident that for the most part these displays rely on bodily interaction. I had built systems around these modalities before and while they were entertaining to a certain point, I found that the interaction quickly reached its limits. Often the experiences with such works were shallow, almost gimmick-like, and very rarely would people want to dive deeper or repeat the experience.

I wanted to try something different and during preliminary research on interactive displays I stumbled across a paper by Eriksson and her colleagues (2007). In their paper they described their project where

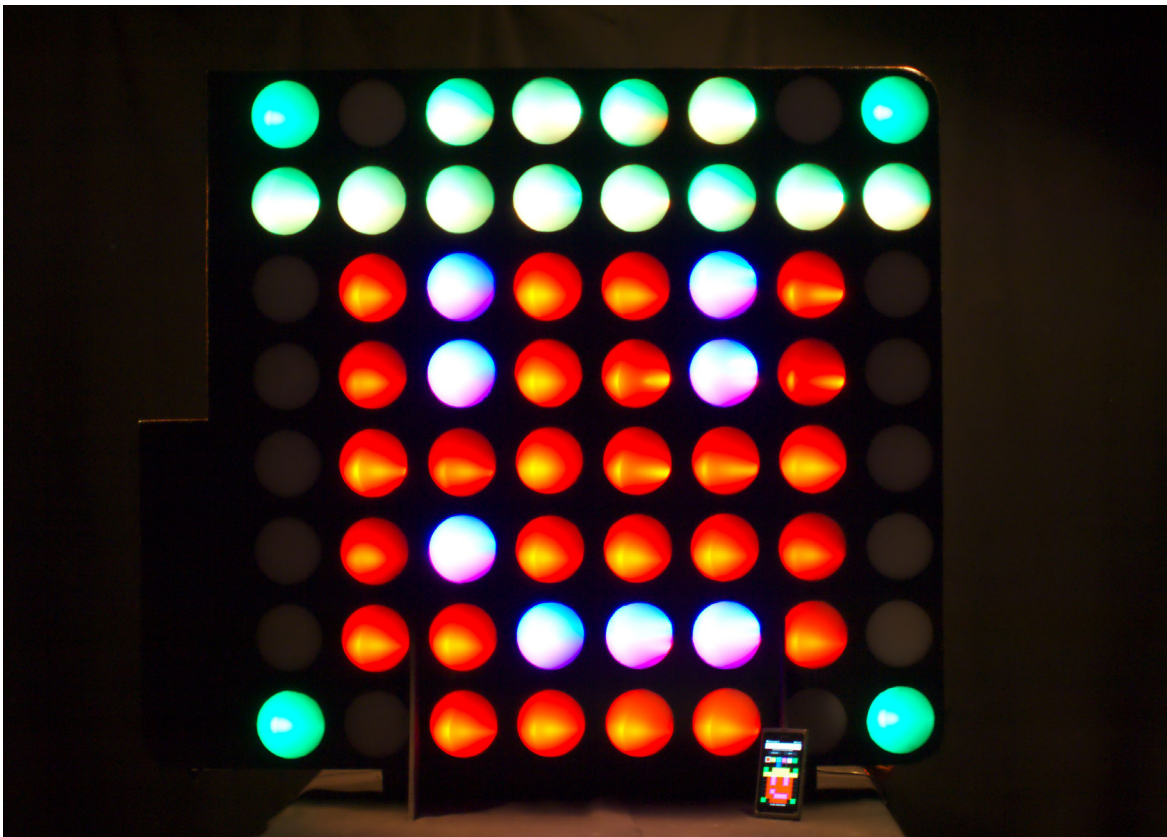
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1 <http://www.graffitiresearchlab.com>

2 <http://blinkenlights.net/>

mobile phones provided the main modality. Their system was based on Bluetooth and required physical presence, I wanted to take one step further and allow anybody around the world to control the system. The interface would be built using the latest web technologies and work through any modern web browser.

The concept started materializing under the name Dotted Landscape. The purpose was to build an attractively designed light panel with interaction possibilities that would allow people to control and play with it. To ease the building I decided that the device would be placed inside a safe environment indoors. Two examples of ideal locations include a hotel lobby or a café. These kinds of locations would also work well due to the actions there being mostly leisure related as this greatly increases the chances of interaction (Müller et al. 2010).

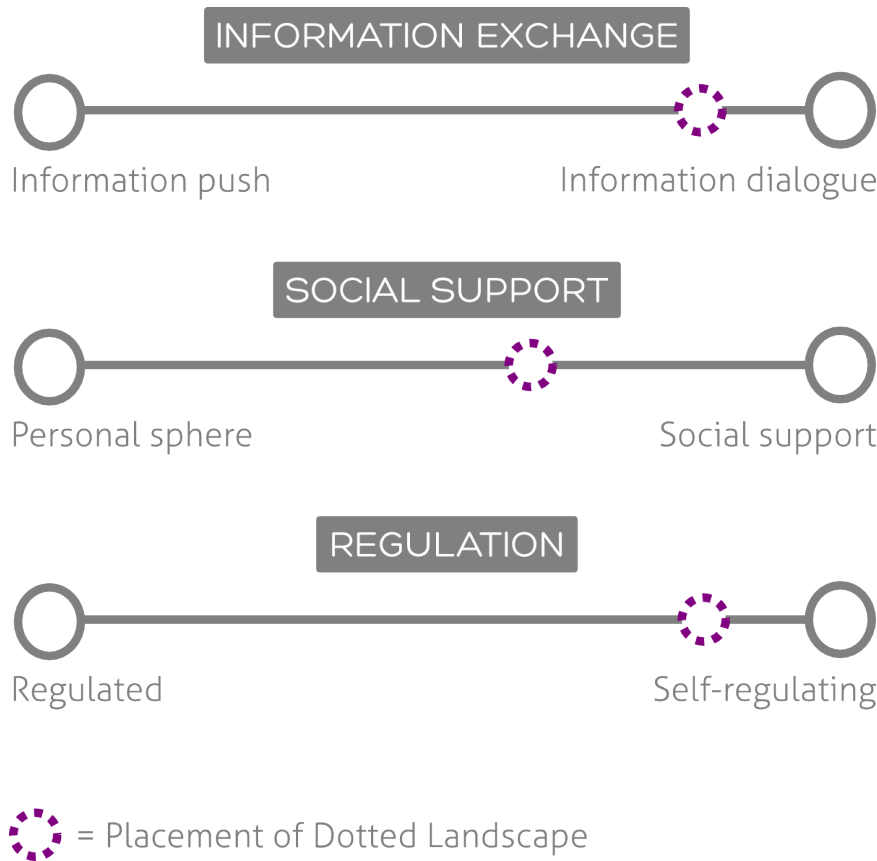


**Image2: The Dotted Landscape light panel and a mobile phone displaying the web-based user interface.**

Inspired by Scandinavian design and Ben Shneiderman's direct manipulation principles (1997), the exterior form and the software user interface both follow simple lines and minimalistic use of graphics. These design decisions are further elaborated in Chapter 3. Before these more concrete design phases could be started, I needed to develop the actual concept. What helped me during this phase is discussed next.

## 2.1 Three design aspects of interactive public displays

To aid the design of interactive displays, Eriksson and her colleagues introduce three aspects that should be considered (Eriksson et al. 2007). The aspects are *Information exchange*, *Social support* and *Regulation*. Each forms a linear continuum where the designer can place her concept. The underlying diagram shows a quick overview of the aspects and an approximation of where Dotted Landscape is situated.



**Illustration1:**  
Three design  
aspects and the  
placement of  
Dotted Landscape.

Information exchange reflects the type of information sharing the technology supports. At the other end of the spectrum we have *information push*, which describes a one-way technology mainly created to publish content coming from a privileged source. This category of technology includes almost everything present in our current society: advertising, infomercials, information displays and road signs are all technology designed for information push. The other end of the axis is *information dialogue*. This type of technology promotes the conversation between participants in the public space as well as the system owners. Examples can be found in some mapping solutions and dis-



cussion boards on-line but very few exist as static, physical extensions of our public space.

The aspect of social support describes how the technology aids the interaction between people. Most technology we have these days revolves around what Eriksson and her colleagues call *personal sphere*. Even though our public locations are filled with technology ranging from wireless networks to ubiquitous mobile phones, this technology is not helping us connect to the people physically close to us. The technology does not exploit the fact that the usage is happening in a shared space, instead it only provides us an extension of our private lives. A valid design challenge would be to create technology at the social support side of the axis. This type of technology would support interaction within the physical confines of our public space.

The third aspect – regulation – looks into the way the technology is controlled. Many of our current technologies reside in the regulated end of the spectrum. These kinds of technologies impose a strict set of rules on their usage. While these rules are often there to protect our safety, they many times fight the essence of public locations that act as the hubs of political demonstrations, sports celebrations, carnivals, music and dance. I agree with Eriksson's group that while safety should be considered it is also worth remembering that public spaces are meant to be alive and partly out of control. This means that any public technology should consider its location on the axis of regulated and self-regulating. A self-regulating technology will find its own laws and codes.

In my view these aspects don't propose an optimal location for technology, but instead provide a way to put a certain design into context. For some types of technology placement in the middle is not an option and certainly some devices such as alarms are best placed in far left of the regulation axis.

Dotted Landscape supports information dialogue as almost all content on the display is created by the users. On the social support axis Dotted Landscape is closer to the middle as the concrete light panel invites people in the same space to experiment with the technology, but at the same time people from anywhere in the world can participate in the experience through the web. Finally Dotted Landscape is very much a self-regulating system. One can argue that the software and hardware already pose certain regulations on its use, but looking past these into the actual user experience the system does not require registering and all users are considered equal.

## 2.2 Taxonomy of interactive displays

To further map the space of interactive displays Müller and his group present a taxonomy by analyzing a set of existing public displays and their evident characteristics (Müller et al. 2010). The taxonomy is split into two axes: *interaction modalities* and *mental models*. The interaction modalities explain the way the systems can be used. In many cases the displays provide more than one, but usually a primary interaction modality can be pointed out. The mental model of a system depends on the content, physical characteristics and the context of the display. Müller and his team have discovered four mental models: *poster*, *window*, *mirror* and *overlay*.

A device using the poster mental model might react to people around but it will not include them directly in the output. For instance a system might track user location and draw a raincloud, which would move with the user. This can attract curiosity and invite the user to interact more deeply. This deeper interaction can then be enabled by supporting other input mechanisms such as touch.

Devices in the window category show the input of another device. One notable example is the Hole-in-space<sup>3</sup> project where a live satellite connection was setup between New York and Los Angeles, and people at both ends could see a real-size projection of a street in the opposite coastal city. Interaction can be initiated when a person wants to see if the people in the display will react to what she is doing. This means that the interaction is lacking without somebody present at the other end as the system itself is just a channel. Mirror devices take the image of passersby as input and transform it in some way for the output. In contrast with the poster mental model, devices implementing the mirror model make it clearly apparent that the user is present in the output. These augmentations in the users view of self may then invite her to explore the interaction.

Overlays are mirrors that present an exact copy of the physical world and add some kind of a modification. This modification is not targeted directly at the users but at the surrounding environment. For instance a display might introduce a virtual animal that reacts to the movements of people in front of the display. Curiosity might raise if people are interested in how the animal reacts to their gestures.

The table below summarizes the taxonomy. Many of the projects listed are not described here separately. Dotted Landscape is placed in the model as well. The interaction modalities are further distributed on an axis between explicit and implicit interaction. In the taxonomy the models that are more inclined on implicit interaction are the ones on top and going down the modalities become more explicit.

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3 <http://timeline.1904.cc/tiki-index.php?page=Hole+in+Space>

Interaction modalities	Mental Models			
	Poster	Windows	Mirror	Overlay
Presence	Hello.Wall, BluScreen		Palimpsest, Videoplace, Vision Kiosk	
Body position	Cylindrical Screens			
Body posture				Jumping Frog
Facial Expression		Hole-in-space	eMir	
Gaze	ReflectiveSigns			
Speech				
Gestures	Interactive ambient public display, Pendle		Magical Mirrors	Diaper Selector, Travelling TicTac-Toe
Remote Control	Touch Projector, Dotted Landscape			
Keys	Opionizer			
Touch	CityWall	ShadowBoxing		

**Table1: Public display taxonomy adapted from Müller et al. (2010).**

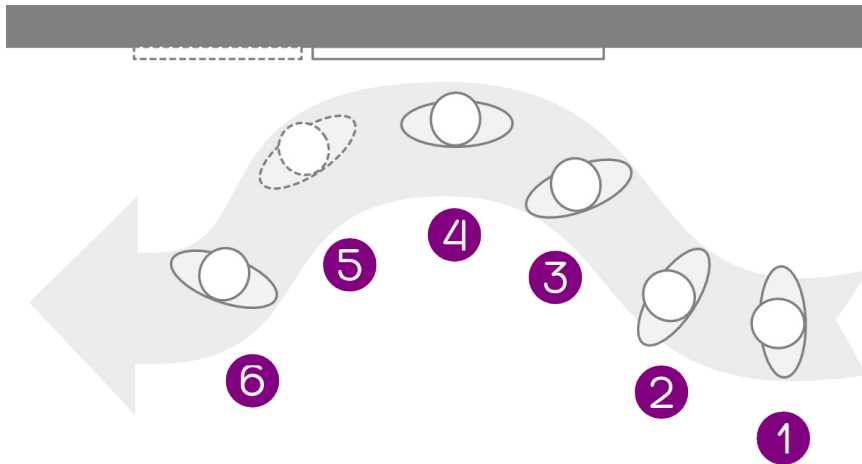
As stated by the authors themselves, one problem with the taxonomy is that many devices match several categories. Looking at their original taxonomy one can see that the poster category is filled with the most projects. In my view this hints at a possible need for a fifth mental model for better classification.

Even if limited, this kind of taxonomy can yield many benefits for the designer during the concept phase. For instance by placing one's concept into the taxonomy other relevant work can be spotted for benchmarking and inspiration. This lead to the inclusion of Touch Projector in the related work section. In addition reflection on the work becomes easier when utilizing a larger generic framework.

## 2.3 Understanding public display usage with the Audience Funnel

As stated earlier, traditional Human-Computer interaction (HCI) rules don't directly work with public displays. To understand the usage scenario better, we can use Audience Funnel – a model first described by Michelis and Müller (Müller et al. 2010). The model describes the stages of usage between a person and an interactive display. The funnel is separated into six distinct phases:

1. Passing by
2. Viewing and reacting
3. Subtle interaction
4. Direct interaction
5. Multiple interaction
6. Follow up actions



**Illustration2: The six phases of the Audience Funnel.**

The model provides no way to rationalize about the quality or enjoyment of the interaction but it provides a way to see the challenges in initiating it in the first place. To provide a better level of understanding I will briefly go through each of the levels and then describe how the funnel helps in directing the design of Dotted Landscape.

### *From passing by to reaction*

The passerby is initially unaware of the interaction possibility with the device and so the first challenge is to awake interest. This is also the most evident difference with traditional HCI scenario where the interface has the full attention of the user in the beginning. The phase becomes even more challenging for the designer in public spaces where our vision and auditory system is constantly bombarded with stimuli.

Generally it is thought that our attention systems are influenced by both a conscious top-down process as well as an unconscious, reactionary bottom-up one (Müller et al. 2010). The top-down process is led by our own goals, such as looking for a certain street sign in a foreign city. More important for attracting attention, the bottom-up process is shared among humans as the result of millions of years of evolution. We tend to react well to quickly approaching elements (animal attacking) and rapid contrast changes. Since this behavior is shared among all humans without culture boundaries, it provides a good model on which to create visual stimuli for displays.

Another model for predicting stimuli effect is *Bayesian surprise*, which measures the difference between our posterior and prior beliefs about the world. In this model the weight is given for subjective beliefs instead of objective probabilities. Other research also shows that locations of high entropy, contrast, saliency, flicker and motion attract human attention, but using Bayesian surprise designers can guide the human eye even more reliably (Itti and Baldi 2006). This requires understanding the placement context and potential user mindset to know what kind of stimuli would be surprising.

Related to the initial attraction phase, the *Honey-pot effect* is widely discussed in public display research. Originally introduced by Brignull and Rogers (2003) in their Opinionizer display project it describes the exponential growth of interested users once a certain usage level has been reached.

It is evident that attention attracting is one of the key aspects for successful public display design. The usage of quick changes in contrast, Bayesian surprise and other methods should be considered but the transition to the next usage phase must be seamless to avoid losing the attention already gained.

In Dotted Landscape making the whole panel blink continuously when there is no direct interaction would probably catch the attention of passersby but would not arouse their curiosity or invite them to interact. For this reason a separate player is designed to care of idle content. The panel alternates between the animations, generative content such as Conway's Game of Life and messages hinting that interaction is possible.

### *Interaction and follow up actions*

Designing for the interaction phases of the Audience Funnel is probably the most central part of the process. This phase presents a number of additional challenges posed by the public nature of the location. Müller et al. mention first the challenge with the presentation of self in a public space. They describe one way of understanding our public behavior as the separation of a *back stage* and a *front stage*. For in-

stance a policeman can act very differently while wearing his uniform when compared to the way he acts among his peers. The peers in this case would present the back stage. In the front stage the officer might evade interaction with a public display all together to maintain his role as an officer of the law.

What interaction methods are acceptable depends largely on the person and the surrounding culture. For instance an introverted person may find it difficult to do bigger hand motions in order to avoid unwanted attention, while an extrovert might take the opportunity to put on a show. Certain gestures such as bowing often have cultural significance and their use should be considered in the surrounding culture. Another challenge is presented with the placement of the display. For instance placing the system in a thoroughfare, such as a subway station, could mean that potential users have to stand in the way of others. This could lead to negative motivation due to general politeness towards our fellow citizens. Supporting this Brignull and Rogers identified in their research that social embarrassment is a key factor in the resistance to start using publicly placed interactive displays (2003). It is evident that considerable thought must be used when thinking about the on-site placement and usage scenarios.

Placing a display in a public venue also means that most of the time people around the system have other agendas on their mind. They might be out shopping, going to the dentist or late for an appointment. In these cases trying to make the potential users diverge from their own trajectories is especially difficult. Müller and his group conclude that if the user's goals happen to be leisure related, such as strolling around, the probability of interaction with the display is much higher.

In addition outdoor spaces present a new array of possible challenges, such as weather conditions and sunlight reflecting directly on the display surface. The conditions also affect the people passing by who might not be interested in stopping if the weather is bad. On the other hand the weather can also be used as a strength. For instance it is worth considering if placing the display in a location where people often come to seek cover from the rain might increase and deepen the interaction.

Once the passerby has noticed the display *subtle interaction* can occur. This is only possible with devices that support direct interaction mechanism such as hand gestures, proximity reaction or general movement. During this phase the person is exploring if the display reacts to her movement in any way. A reaction from the display is required to assure the person that interaction is possible.

After subtle interaction the person might move on to the phase of *direct interaction*. Now the user is engaged with the display in much

more depth and pursuing her own goals. After this *multiple interaction* is possible when there are multiple displays next to each other or when the user leaves the display only to return later on.

*Follow up actions* describe the last step. During this step a variety of scenarios might occur. For instance a previous user might take a photo of the device and stay close by to observe how others use the same system. In my view these kinds of post-usage actions could also be supported by the system. For instance Facebook sharing or joining a mailing list might be offered during the interaction.

In addition to thinking about these four phases, the display designer should make sure that the transition from one phase to the next is seamless. If all four phases are wanted, then considering a combination of interaction modalities could be useful as some, such as bodily interaction, better suit the subtle interaction phase and others, such as touch and keys, are more suitable for deeper, more controlled interaction.

Unfortunately on its own Dotted Landscape provides no direct support for the subtle interaction phase. To alleviate this problem a tablet computer could be placed in front of the panel to display the web-based user interface. This would enable the user to quickly try touching the UI and seeing if anything happens. Furthermore a web address could be placed next to the panel so that people could reach the direct interaction phase without needing to use the mounted tablet computer.

The multiple interaction phase could be supported by providing the users the possibility to save their animations on the display and leave comments in a guest book. This creates the need to return to the piece later on. For instance an animation author might come back later to see if her animation is among the most played ones. Commenting possibility on the web site provides a feedback mechanism that also has the potential of making people return. By showing possible replies only on the panel website, the user must return periodically to keep up with the conversation.

## 2.4 *The challenge of motivation*

Motivation is another challenge that differentiates public display design from regular human-computer interaction. In comparison with traditional home computers, the users of public displays normally don't go looking for the devices nor are initially motivated to use them. When comparing with traditional paper-based media in public locations, the public displays need to motivate the users past the reading phase into the interaction.



Despite being an increasingly important topic in our current computer filled world, only few works regarding motivation exists in HCI research. In their paper Müller et al. (2010) build upon the prior work of the Magical Mirrors study, where a list of five categories affecting motivation is presented. These categories are *challenge and control*, *curiosity and exploration*, *choice*, *fantasy and metaphor* and *collaboration*.

*Challenge and control* reflect on the motivational increase in mastering an interaction while at the same time staying challenged by it. This is also presented as the *flow*, which is achieved when the interaction is difficult enough to stay interesting but not too difficult to make the user anxious. In the Magical Mirrors study the possibility to see the consequences of one's own actions was the most important factor in motivating via challenge. In creating the challenge a set of goals need to be decided by the designer, but room should also be left for emerging new goals from the users. The motivational factor of control is based primarily on the observance of cause-and-effect chains between the users actions and results presented by the screen. Powerful effects and the level of freedom the user has in choosing her actions also increase the sense of control. To get the motivational effect the subjective feeling of control is more important than actual control.

*Curiosity* stems from our internal need to avoid insecurities. For instance exploration is done in unknown environments to avoid the feeling of insecurity. In motivation curiosity forms one of the most important intrinsic factors. On a general level curiosity is triggered by novel stimuli that presents something unclear, incomplete or uncertain (Müller et al. 2010). In design this means that the display should not be created in a way that is either too complex or too trivial. The used elements should be surprising but not incomprehensible. The user should have initial expectations of how the interaction proceeds, but these expectations should only be partially met by the display. This results in a balancing act. Müller's group suggests that the desired interaction can be initiated through surprise and then maintained with constructive elements. Sensory curiosity can be achieved with perceptible stimuli, while cognitive curiosity relies on what is anticipated.

The motivational increase via *choice* happens when the user can select between several alternatives. Obviously as the amount of choices increase, the probability that a matching preference is found improves. However the designer must again balance between providing too many alternatives and providing too few to maximize the amount of intrinsic motivation. Rules of thumb, like the Miller principle<sup>4</sup> of providing only  $7 \pm 2$  options, can be considered here. A certain overlap can be seen between providing choice and allowing control to the user, both of which increase intrinsic motivation.

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4 [http://en.wikipedia.org/wiki/The\\_Magical\\_Number\\_Seven,\\_Plus\\_or\\_Minus\\_Two](http://en.wikipedia.org/wiki/The_Magical_Number_Seven,_Plus_or_Minus_Two)



*Fantasy* elements have been found to have an increasing motivational effect as they allow the user to cut down the constraints of real life and possess imaginary powers. This might mean that lifting an object in the display would be more motivating if the user thought that she had the power of telekinesis than just presenting a hand on screen for dragging. Metaphors can be used to guide the users and explain new interface elements.

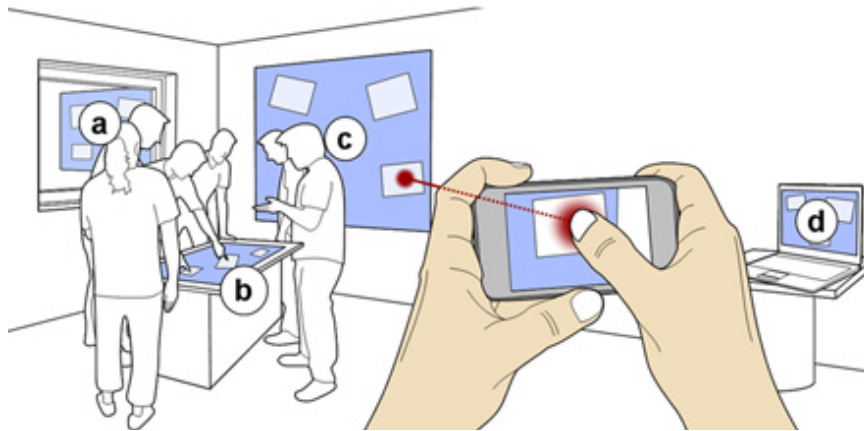
*Collaboration* works differently from the other motivational factors because it is triggered by the opportunity to influence the actions of other people. In this sense the design focus moves to enabling collaboration in the system. Also important is the way that individual actions are presented in the screen as the motivation becomes much stronger when one's own actions are recognizable by other participants. The value given to one's actions by others leads to the repetition of that behavior. Müller's group reminds that behavior related to collaboration is very much tied to culture and society norms.

Dotted Landscape employs no direct ways of fantasy elements or complicated choice paths. The main motivational element is curiosity, which is fueled by keeping textual information in the interface to a minimum. The user finds out how to use the device by touching, playing and experimenting. Another motivational factor comes from the feeling of control when one crosses the gap from the user interface in the digital computer into the physical world where the actions directly affect the lights in the space.

The synchronous features employed in Dotted Landscape provide a strong possibility for the collaboration aspect. Actions made by the participants immediately affect the views of all others as well as the panel. The worst case scenario involves one user taking full control and flooding the device with commands, but the system could also be used for a dialogue, communication with or without words between people on opposite sides of the world. One challenge is to provide a concise representation of who did what action on screen. For this, temporary colors tied to a certain connected device can be employed and quickly shown when that device is interacting with the panel.

## *2.5 Related interactive works*

In this chapter I briefly look at six related projects. Each is discussed in the context of Dotted Landscape and an attempt is made to learn from their success and shortcomings. The three first projects are more research-oriented and aimed for actual usage scenarios, while the rest represent a more artistic direction.



**Illustration3: The principle of the Touch Projector.** Letters a, b, c and d point out the various places where the user can point her device in order to interact with the elements.  
© Hasso-Plattner-Institut

### *Touch Projector*

This project was chosen for its identical location in the display taxonomy presented earlier. The similarity in interaction modality and mental model makes it a good candidate to learn from. However further research showed that relying solely on the taxonomy is a poor way to compare projects on a practical level.

Touch projector uses a client-server model to enable the usage of mobile handheld devices as controls of larger displays (Boring et al. 2010). For instance the user can see a projected surface in a distance and by pointing the camera of her handheld device towards the surface, she can control objects on the larger display and even move them from one display to the other.

The system is build on top of an Apple iPhone 3G smartphone and requires special software to be installed. Evident from the research is the emphasis on evaluating the interaction mechanism and a good amount of user research was done to find optimal ways to provide this remote way for direct touch manipulation. As such it does not lend much inspiration for Dotted Landscape apart from some insight into the direct form of interaction and suitability of mobile phones as the main modality.

### *Plasma Posters and WebWall*

Plasma Posters was built as a joint venture between the University of California and the FX Palo Alto Laboratory to provide a system that facilitates the sharing and annotating of web content (Carter et al. 2004). The posters are wall mounted displays that users can control with PDA devices. Users can post content by sending email or submitting it through a web interface. Typical content includes web links, text, images and short movies. These can then be annotated by other people accessing the screen through a touch-based interface or people using a specified application on their PDA devices.

The WebWall project is very similar to Plasma Posters as it also allows people to access web and share content through large displays by using mobile devices. The system employs the common client-server architecture where a user with his mobile device can access a WebWall through several channels including SMS, email, HTML-pages and direct HTTP-calls. The server then handles the requests and forwards them to the appropriate display unit (Ferscha and Vogl 2002). Each action needs to explicitly define the target WebWall by using the ID of the display in question.

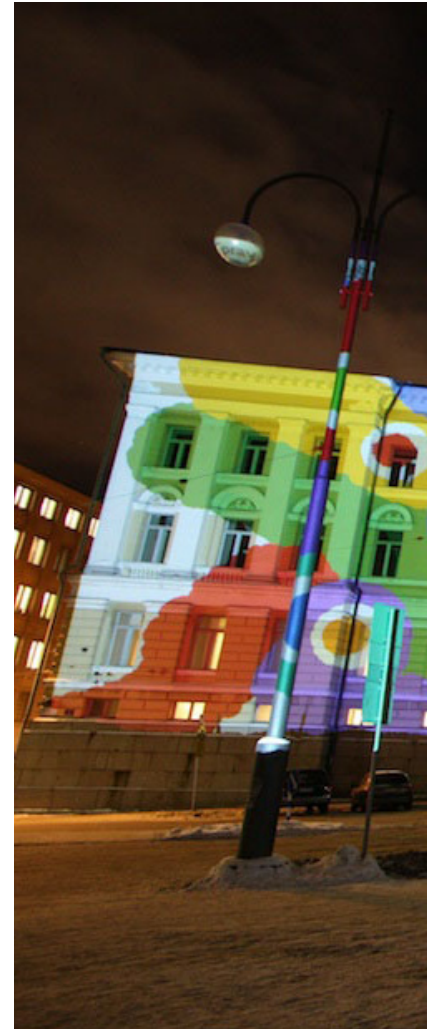
The idea for commenting in Dotted Landscape started from the Plasma posters. Like Touch projector these two projects verify that our current mobile devices can be used as very powerful remote controls for larger displays. However, I wanted to evade the complexity introduced from building a native application by implementing the user interface with standard web technology.

### *MobiSpray*

The combination of a video projector and a mobile phone is used to create an interactive art tool that enables up to four people to paint on an existing surface such as a building facade. MobiSpray sessions have been conducted in over 50 cities around the world, giving local architecture new meanings through the use of bright colors, text and embedded images (Scheible and Ojala 2009).

Participants paint by using a Nokia phone equipped with special software that generates draw commands which are then sent to a server that renders them for the video projection. Guiding the paint cursor happens by moving the mobile phone, and the keys on the phone are used to select the active drawing tool.

What inspires me in MobiSpray is the immediateness of the experience and the disruption of everyday space. People that happen to walk past can easily participate and the results are visible in real time. Unfortunately these kinds of projects only exist for a few hours at a time drastically limiting the amount of participants. Also there is no built-in support for follow-up actions or any way to take something





home after the session. For instance the system could support saving the rendered images and sending them to the participants via email.

### *Vectorial Elevation*

Vectorial elevation uses a set of robot controlled searchlights that can be moved individually. The users of the system can create their own dances of the lights through a web interface, save the designs and then play them later. The light installation is video broadcasted live so that people from the other side of the planet can enjoy the show. Since the first installation in the central square of Mexico city, Vectorial Elevation has toured around the world (Manovich 2006). The current installation in the beginning of 2012 is in Vancouver, Canada (Vectorial Elevation 2012).

The web-based design interface is fairly advanced and allows creation of complex light choreographies. However the queues to get your light

**Image3:**  
**MobiSpraying**  
**the University**  
**of Helsinki.**  
© **MobiLenin**





**Image4:**  
**Vectorial**  
**Elevation in**  
**Boston.**  
© Maurice Li

show to display can be quite long and the lack of an immediate reaction from the light piece troubles me as it removes the possibility for a subtle interaction phase as described in the Audience Funnel chapter. Clearly the motivational factors behind Vectorial Elevation are much more based on the sense of awe and power when creating these huge displays of light.

### *Blinkenlights*

Blinkenlights<sup>5</sup> is one of the major inspirations for Dotted Landscape. This large-scale light art project turns entire buildings into light panels by installing a huge amount of lights in front facade windows. Mobile control enables users to participate and create new content. By using desktop computers, users can install free software provided by

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<sup>5</sup> <http://blinkenlights.net/>



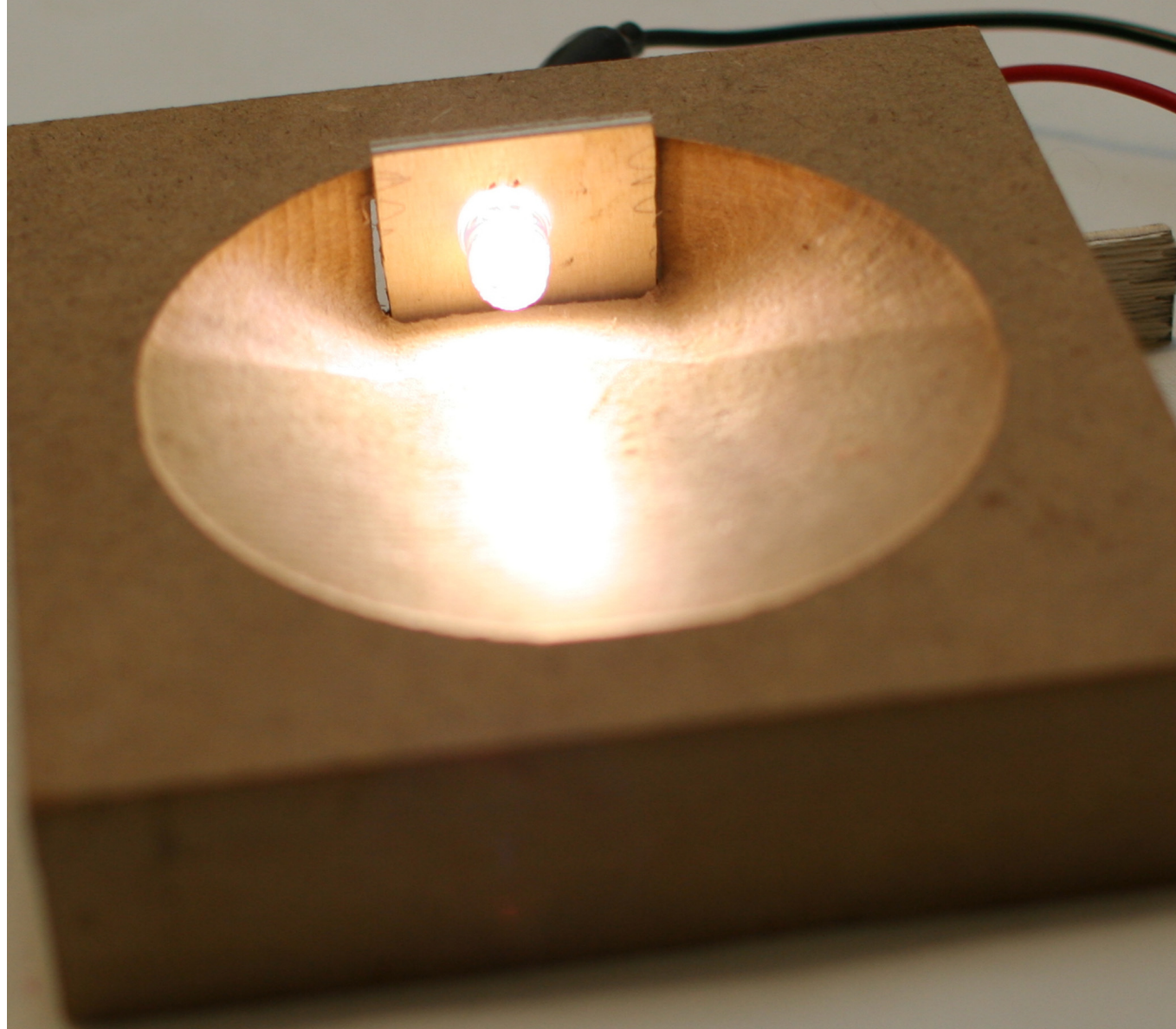
the project and create animations that are played on the facades.

The audience participation and the sheer size of the visuals are inspiring. Also the retro arcade style of the graphics verified to me that very nice animations can be created even on the 64 pixels of an 8 by 8 matrix. The best contribution from the Blinkenlights project comes in the form of open source code. Their software is freely downloadable from their website and the flexible licensing allowed me to incorporate parts of their design in Dotted Landscape. More details about this process are discussed in Chapter 4.

For me, one of the sad points in Blinkenlights is the performance nature of the light displays but understandably the building facades are not lit for months since the buildings themselves need to be used for other purposes.

**Image5:**  
**Blinkenlights**  
**project in Toronto.**  
© City of Toronto





### 3 Creating the form and the interface

The form creation of Dotted Landscape happened in five phases: initial rough sketching, early 3D-models, prototyping with cardboard, more detailed 3D-modelling and then the actual hardware production. The interface production proceeded in parallel with initial sketching leading to implementation and further iterations through user testing and new feature ideas.

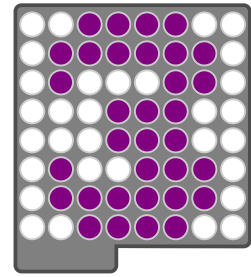
In this chapter I will outline the process in chronological order starting from the inspiration, early models and prototyping to a quick recap of the production phase. After dealing with the form I will explain the user interface design and production process.

#### 3.0 Inspiration from Scandinavian design

In her book Eileene Harrison Beer describes Scandinavian design as timeless in form and excellent in quality (Harrison Beer E. 1975). It emphasizes the proper usage of raw materials and their natural beauty. In this sense Scandinavian design shuns any kind of mimicry or make believe. Since the Paris Exhibition of 1925 this school of design has enjoyed success especially in interior design. With the omnipresence of Ikea furniture, Scandinavian design has become a part of homes all over the world, while the classical pieces such as Eero Aarnio's Globe chair and Tapio Wirkkala's carved dishes have become luxury items.

The simple forms and use of wood are the characteristics that influence me the most. Unfortunately not many studios successfully combine high-end technology with beautiful Scandinavian form. One exception is the Danish world-renowned company Bang and Olufsen<sup>6</sup>, but their designs – ingenious as they are – appear metallic and cold for me. I wanted something that combines the use of wood with lights, electronics and interactivity.

The Brasilia table by Eero Koivisto and Ola Rune was one of the major inspirations in the initial form design. The table is built out of a continuous loop of molded veneer layers that show no visible joints, while still revealing the beautiful wood texture. The flowing form fascinated me and although more angular form alternatives and other materials were considered, the wood veneering and soft shape persevered as the main inspiration throughout the process.



<sup>6</sup> <http://www.bang-olufsen.com/>





**Image6:**  
**Brasilia table**  
**by Eero Koivisto**  
**and Ola Rune.**  
© Swedese.se

### *3.1 Designing the form of Dotted Landscape*

After the initial idea, the work started with rough sketches using pen and paper. The rigid form of an 8 by 8 matrix and the objective to build it as a wall panel provided easy constraints to the design. Although a larger size would have been possible with more complex hardware setup, the 8 by 8 matrix provided a nice, retro look while being useful for simple animations.

Another early decision was the use of three LED lights per spot. A combination of red, green and blue would enable me to display a variety of colors. An alternative to this would have been to use one RGB LED capable of creating different colors on its own, but comparing the amount of lumen given per Euro it was evident that the three-led-approach proved much more cost-effective. One option would have been to use several RGB LEDs wired in parallel to emit more color or use one high-power RGB LED, such as the Luxeon Tri-Star<sup>7</sup>. However using normal RGB LEDs would have resulted in more complicated setup due to the need to change the LED voltage for different colors and the Luxeon would have been around 14 times more expensive than three 10mm LEDs as one Luxeon costs around 17 USD and one 10mm LED is about 40 cents.

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<sup>7</sup> <http://www.luxeonstar.com/Predefined-RGB-LED-Assemblies-s/230.htm>



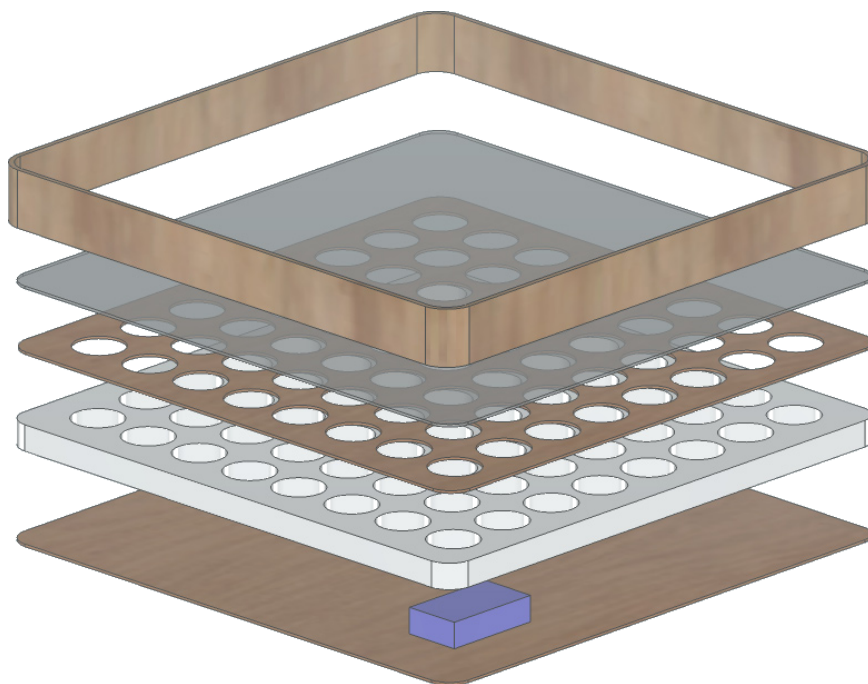
Regarding the materials a mixture of wood and acrylic glass allowed the creation of something that resembles furniture but allows the use of light. The acrylic front panel also diffuses the hard light coming from the LEDs. These materials are also very common in Scandinavian design and easily available for relatively low cost.

The dimensions of the panel were the first variables to be nailed down. I decided on a form of 1 meter times 1 meter with round LED spots with a diameter of 90 millimeters. This provided padding on the sides while still keeping the spots quite large. The thickness was nailed at 30mm plus the acrylic front and plywood back, making the total thickness just above 40mm. In each light spot the LEDs would be placed in a cup-shaped sink. This sink would be 20 millimeters deep.

### *3D-design*

A model was drafted as a communication tool and validation for the measurements and ideas created during sketching. The quickest approach would be to do a technical drawing on drafting paper but I was also interested in playing around with different dimensions and materials, and thus resorted to computer-aided 3D-modelling.

**Illustration4:**  
**First blowout**  
**diagram of the**  
**panel structure.**



I chose Google Sketchup<sup>8</sup> as the modeling tool. This phase was extremely helpful in identifying problems and shortcomings in the initial designs. Using the renderings of the model I was able to create a quick overview of the project to help explain it to others.

The initial idea was to build the core of the panel – depicted white in the blowout diagram – in Styrofoam to make it easy to create the cup-shaped LED sinks. However, I was instructed by the Set Construction workshop master at Aalto University's School of Art and Design that this material wouldn't support the panel very well. I would be better off by using a milling machine at the Industrial design department to create the core out of medium-density fibreboard (MDF).

With the 3D-model ready I approached the Industrial design department. I met the workshop master there who instructed me to approach the matter in a bottom-up fashion by first designing a single LED-spot in the matrix and then multiplying that design for the whole panel.

Although this meant that I had to backtrack a bit from 3D-design, the bottom-up process proved much more suitable than my initial *top-down* approach. Mostly because in this case the smallest solution had the biggest effect on the panel. To decide which kind of light spot would be ideal I had to come up with a way to experiment with different alternatives to combine three LEDs. The bottom-up process also revealed crucial questions regarding physical attaching of the LEDs as well as placement of the wires.

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<sup>8</sup> <http://sketchup.google.com/>

## *Experimenting with LED sink forms*

The 64 sinks that contain three LEDs each can be seen as the most basic unit of construction in the panel. Although seemingly simple at first glance, these sinks can be implemented in a variety of different ways. In addition to the even and efficient distribution of light, the placement of electronics and the ease of construction also have to be taken into account.

One way to test the forms would be to construct digital 3D-models, place light elements into them and render them using a ray tracing method that simulates the light conditions fairly realistically. I chose a more concrete way of building simple prototypes from paper and cardboard. This approach gave me first-hand knowledge on the suitability of the models in the actual construction.

I decided to test three different options regarding the overall form. Each with two different surface materials. I also varied the bottom construction of the sinks with some of them having rising floors and changed the positions of the LEDs from a simple row into placing them around the rim of the sink. In the end I had 8 different sinks for the first round of testing. The overall form was either circle, cup or square and the material was either reflective foil or white paper. The aim was to keep the experiment quick and simple without compromising the data. I chose cardboard as the construction material because it is easy to acquire and work with. The sinks were built by bending and combining pieces of cardboard with tape and covering the upper side with either normal white paper or reflective foil.

All three LEDs were connected in parallel and run at a constant voltage of 3.2V, which is slightly too high for the red ones as the announced maximum for them is 2.4V<sup>9</sup>. For the green and blue LED this voltage falls inside the recommended range. Fortunately the high voltage only burned one red LED during testing. Besides replacing the one LED, the same lights were used in all the experiments to counter any difference in build quality.

To calculate the amount of light and review the light distribution, a photo – such as the one included here – was taken of each variation in a dark room. The camera was placed on a tripod and the distance to the sink was kept at a static 45cm. An ISO value of 100 with a static 9.0 aperture accompanied by an exposure time of 20 was used through-



**Image7: Example of an image used for LED light calculations.**

9 <http://www.ledssuperbright.com/10mm-led-c-9/100-10mm-bright-red-led-70000-mcd-p-100>



out the tests to assure similar conditions. Despite all the work to assure constant conditions, some changes in the camera position happened, which led to varying margins around the sink. This was later taken into account by cropping the photos to only contain the object area and basing the calculations on value averages and not sums in order to remove the effect of image size in the results.

### *Computational analysis of LED sinks*

After all the images were taken it was time to find a proper method for their analysis. Although it would be trivial to open all the photos in a photo editor and examine the color levels there, the process of opening and comparing the levels of a dozen photos might prove to be tedious and ineffective. I decided to build a custom analyzing program using the Processing framework<sup>10</sup>. This allows me to add my own variables and control the data visualization more precisely. Also batch processing all the photos after adding a new one became very easy. The source code for the analysis tool is freely available from the repository<sup>11</sup> of the project.

The photos are placed in the same folder and the filenames are included in the source code. The script calculates the color histogram of each channel along with the average brightness of the image. The data is then displayed on screen. The user can use left and right arrows to navigate between the photos and press 's' to save the current view into a separate Portable Network Graphics (PNG) file.

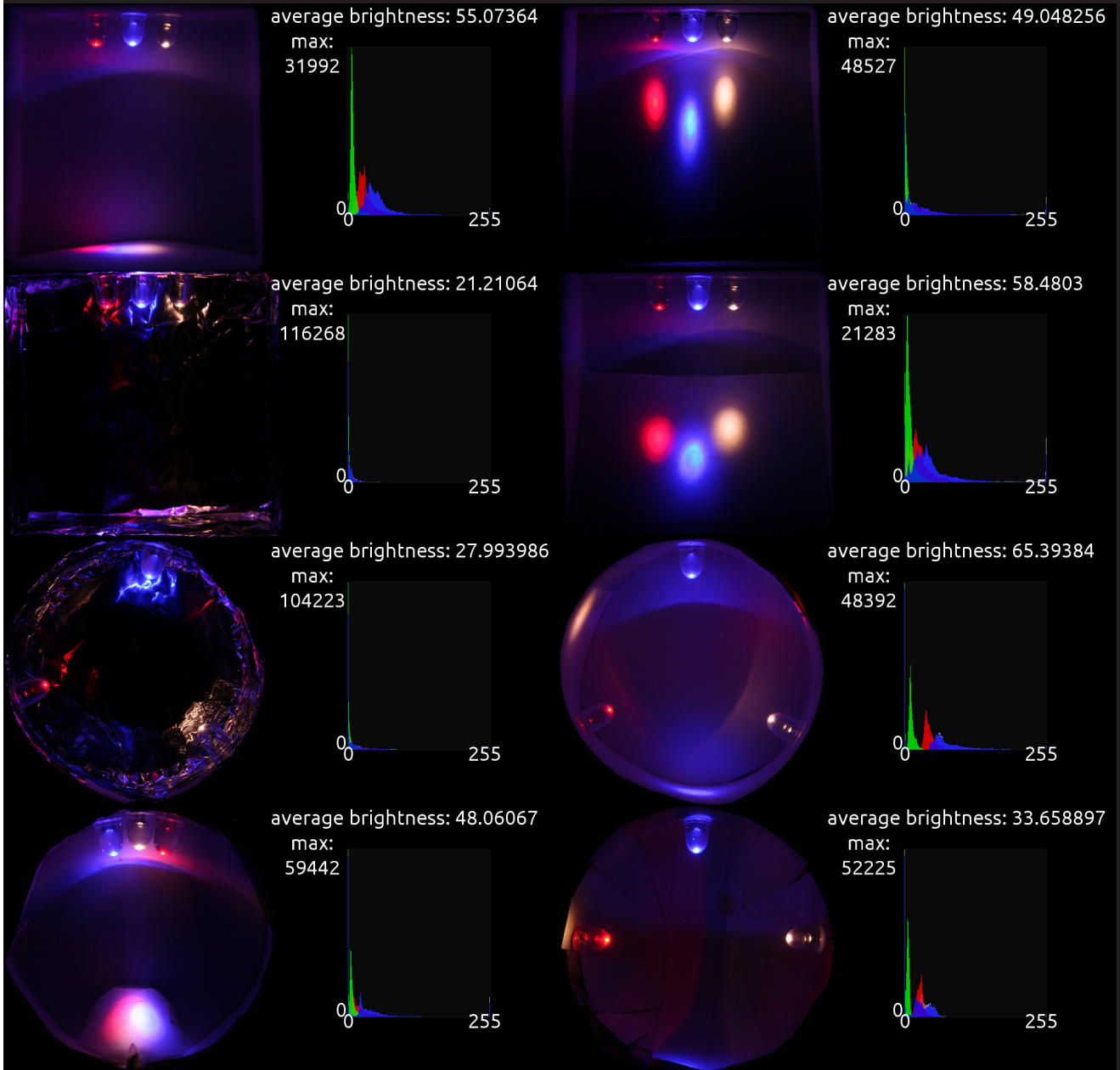
The first experiments tested the overall form of the sink and the bottom material. The image analysis results are included in image 8. The forms included rectangles (first four) and circles (last four). Some had reflective foil as the bottom material (3rd and 5th) while the rest relied on white paper. The form of the bottom and the position of the LEDs were also used as variables.

The first image is a rectangular plain box with white edges and bottom. The second form in the top right is the same except it employs a rising floor that reflects the light upward. The third sink is a foil packed variation of the first. The fourth variation took the second design and moved the floor to incline after the mid-point to give the beam more time to disperse before hitting the it. The fifth design uses a circular shape with foil as the material. The LEDs are distributed evenly on the rim. The next design uses the same structure, but replaces foil with white paper. The seventh design places the LEDs at the top and aims them toward a half-ball embedded at the other end of the sink to disperse the light evenly. The last design variation uses a bottom that is cup-shaped. The LEDs are again placed on the sides.

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<sup>10</sup> <http://www.processing.org>

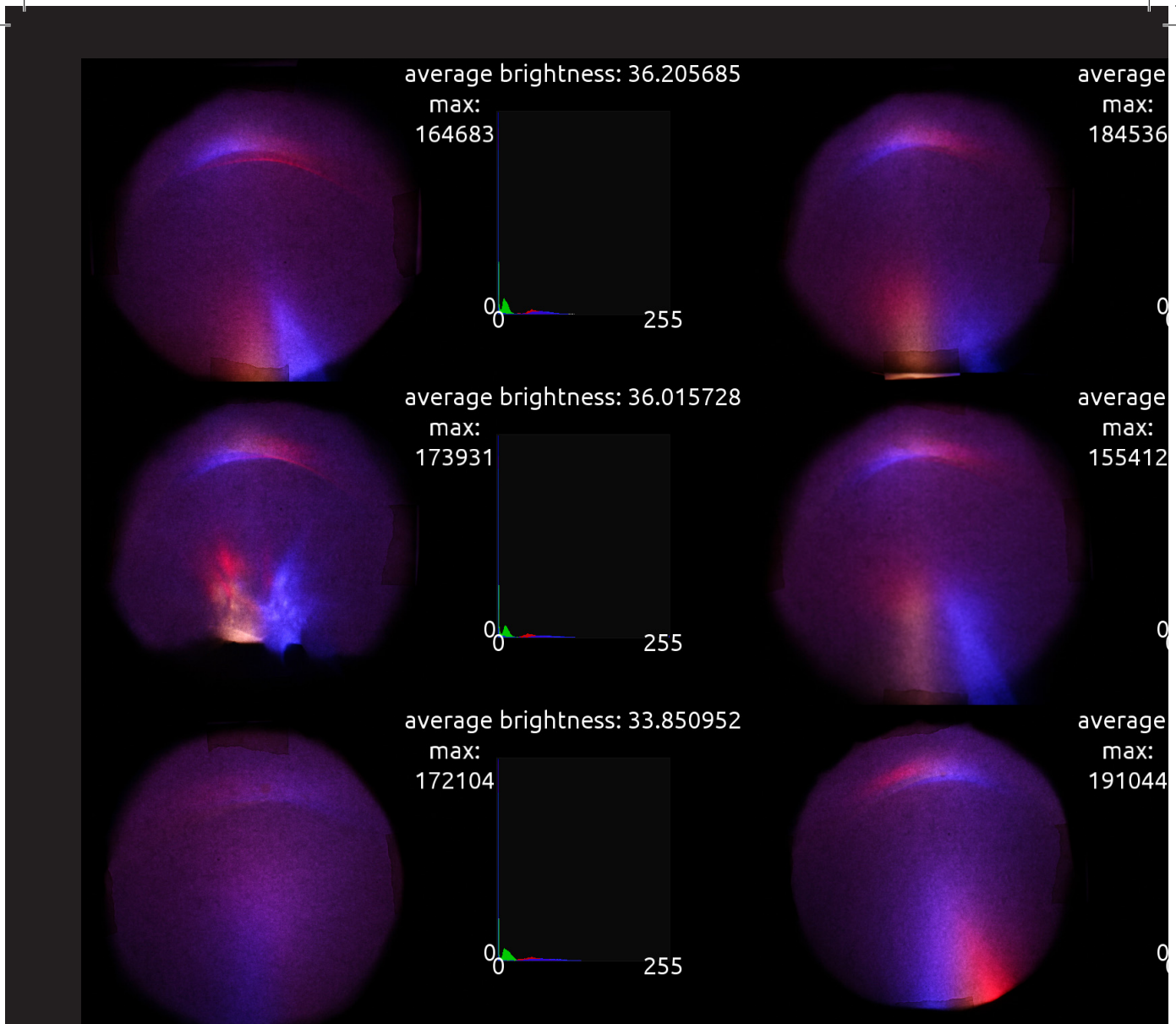
<sup>11</sup> <https://github.com/luopio/dottedlandscape>



In the results the foil versions lost in measured average brightness with a maximum value of 28 from the circular version. This can also be seen from the images where the foil versions create small intense reflections instead of dispersing the light. The other forms had average brightness values of around 50, except for the eighth version that had a meager value of 33. Overall the circle and rectangle shapes were quite even. The circle design at sixth place had the best average brightness of 65 with two rectangles – the fourth and first – coming behind with values 58 and 55. Based on these results the circle form with white coating was chosen as the best alternative.

The winner form was problematic due to the placement and soldering

**Image8:**  
**Composition of**  
**tests on different**  
**LED sink forms.**



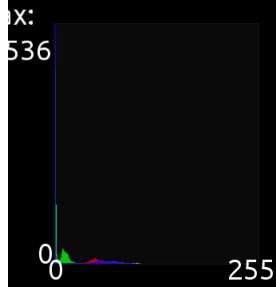
**Image9: Combined analysis images of the circular LED sinks.**

of the LEDs as distributing them on the rim was difficult. Instead they needed to be placed at one end of the sink. To enable this, a composite form was build from the circle shape coupled with an inclining floor that was used in the rectangular form.

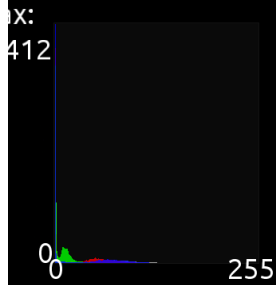
The second round focused on validating the circular shape and thus less variables were introduced. In image 9, the fifth sink has a completely level floor and the third uses foil instead of white paper. The others were identical measurements of the same sink type, but with varying floor inclinations. In these tests the front view of the sink was blocked by a piece of white paper. This enabled the camera to record the form and intensity of the reflection to the top surface, which – in the end – is the light perceived by the audience.

Although all images display different sinks, the numerical values gener-

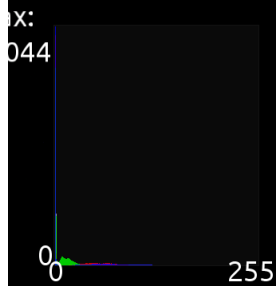
age brightness: 31.37913



age brightness: 40.129868



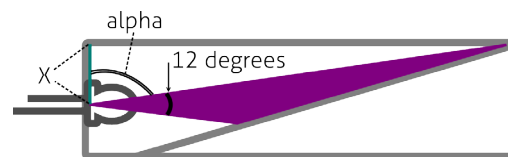
age brightness: 38.56844



ated through the computational analysis are very similar. Overall it can be said that also in these sink variations the ones that use a white paper floor generate a more even light distribution than the foil sink (middle left image). The use of an inclining floor proved out to be good as this raised the average brightness from 30 to 40. Based on these results a white painted circular form with a slowly rising floor was chosen as the most promising option.

### *Finalizing the LED sink form*

After deciding on the form the last step was to calculate the optimum height for the LEDs from the sink floor. Calculating a perfect placement was impossible as the manufacturer reported the LED light angle tolerance to be  $\pm 6$  degrees. This meant that the angle of the LED beam might vary from 6 to 18 degrees between LEDs.



**Illustration5:**  
**Calculation for the**  
**X - optimal height**  
**of the LEDs in the**  
**sink.**

I decided to calculate a satisfactory value by assuming the LED beam was the average value of 12 degrees. My aim was to get the higher side of the beam to hit the sink opposite end as depicted below. The

lower part of the beam would reflect upwards to the sink ceiling. As illustrated, the calculations are simple geometry.

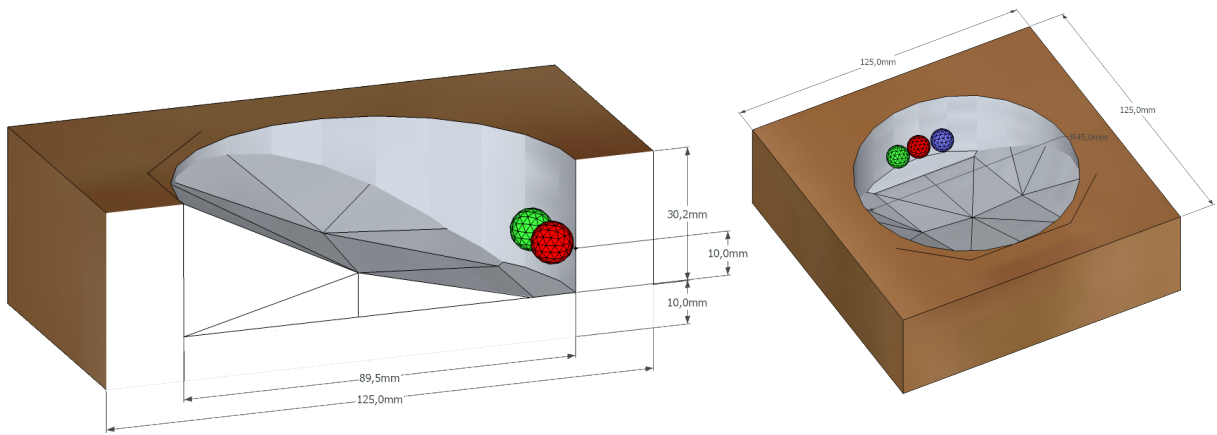
The three lines: sink ceiling, beam higher edge and the X distance on the side form a right-angled triangle. Angle *alpha* and half of the 12 degree beam angle form a right-angle of 90 degrees. Thus *alpha* can be calculated easily:

$$\alpha = 90^\circ - 12^\circ / 2$$

$$\alpha = 84^\circ$$

Knowing one angle and one side of the right-angled triangle we can calculate X with tangent:





**Illustration6: LED sink split view and overall view.**

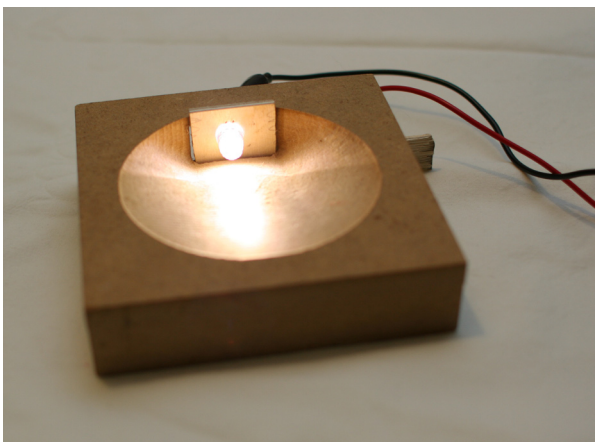
$$\tan 84^{\circ} = 90\text{mm} / X$$

$$X = 90\text{mm} / \tan 84^{\circ}$$

$$X \approx 9.46\text{mm}$$

Knowing that the height of one sink would be 20mm placing the LED into the middle would be ideal.

After designing, the end result needed to be transferred to a 3D-model for the milling machine. Some curvature was added to the final sink floor in hopes to further improve the light distribution. The first version employing the exact calculations was created in Google Sketchup. Unfortunately this version did not work with the milling machine and the model had to be transferred to Rhino 3D.



**Image10: Singular LED sink for testing.**

The problem between Sketchup and the milling machine was that Sketchup stores model data as direct polygons. From the perspective of the milling machine a NURBS-based software would be preferred. NURBS (Non-uniform rational B-spline) modeling software handles model surfaces as curves instead of the block-like approach of polygon-based modeling tools. Without further diving into the issue it is better to check in advance what the milling machine accepts to avoid redoing the models in another software. If NURBS is required then I would recommend using another free tool like Blender<sup>12</sup> instead of Google Sketchup.

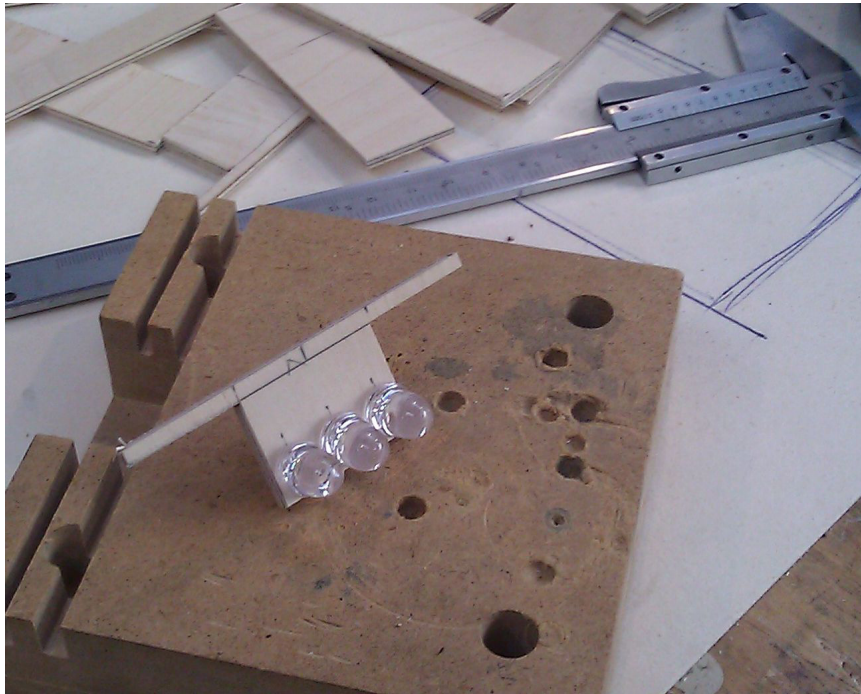
<sup>12</sup> <http://www.blender.org/>

The first product from the milling machine was one LED sink. The purpose was to test this form with actual LEDs and acrylic front glass. The form was quickly validated as a working solution and the final form was created by multiplying the single sink 64 times to form the 8 by 8 matrix.

### *Hardware production process*

An overview of the hardware production process is given here. A more thorough description can be found from the production diary which is included as an appendix.

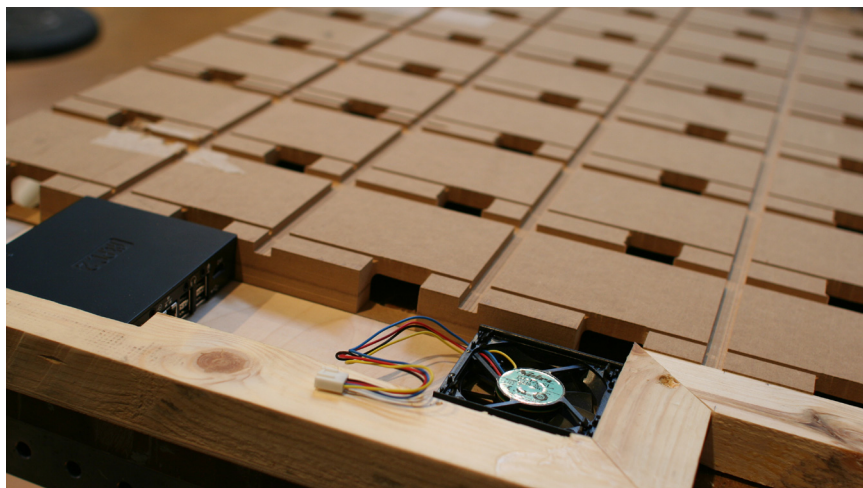
Upon receiving the milled panel made out of medium-density fibreboard (MDF), I started researching for an optimal way to attach the LEDs. The aim was to produce a solution that would allow me to change the LEDs in the future. The front panel would be attached permanently so the LEDs would have to be inserted from the back. The end result was a T-shaped piece where the bottom part would embed the LEDs and fit directly into the slot in the sink. The upper part of the T-shape would fit into shallow slits that were created with a circular saw and fix the piece into position.



**Image11: T-piece to attach the LEDs to the sinks.**

In addition to the slits for the T-pieces, bigger gutters were created to run the wires and a bottom section was added for the computer and electronics. The acrylic glass for the front panel was attached using sheets of contact glue and a detachable back panel was created from

**Image12: Panel backside with sink slots, gutters for wiring, small slits for T-pieces and a compartment for electronics and computer.**



plywood. Once all the layers were attached the final form was created by rounding the edges with a jigsaw. After this the wood veneer for the sides was created out of sheets of birch. I wanted to create a darkly colored panel to accentuate the colors of the LEDs and for this decided to paint the front glass matte black and use stain varnish to transform the veneer sides into dark mahogany color.

The last production phase was attaching the electronics and computer to the panel. The LEDs were tested and placed to the T-pieces and wires soldered to form three separate 8 by 8 matrices out of the 192 LEDs.

Due to the overall process being fairly new to me, the hardware production advanced in iterations with details being designed alongside with production. In the end a very detailed preliminary plan would have enabled me to incorporate designs such as the attachment of LEDs, the wiring gutters, rounded edges and the bottom compartment to the original milled version. This would have reduced the production time drastically. However being aware of these issues before production requires considerable experience, which I didn't have at the time. In this sense the hardware production resembled more of a prototyping workflow than product development.

### *3.2 User interface design drivers*

While designing the UI of Dotted Landscape I wanted to strictly follow the principles of direct manipulation – a concept advocated by Ben Shneiderman since the early nineties. Direct manipulation is a way to approach UI design where user control is put first over system autonomy. I will now explain its three characteristics and their influence on the design in addition to some other guidelines such as Don Norman's affordance principles.

For the visual style I was inspired by the latest mobile user interfaces such as the Metro UI from the Windows 7 phone and the new Meego design by Nokia. Both emphasize simplicity with beautiful typography and spatial interaction metaphors over static graphics and skeuomorphism<sup>13</sup>. This combination also fits nicely with the Scandinavian design inspired exterior form and the principle of avoiding mimicry.

### *Direct manipulation*

The development of interface design as a scientific branch has brought several distinct viewpoints into the field. One persistent divider in interface design is between autonomous agents and direct manipulation. User interfaces that employ autonomous agents tend to favor artificial intelligence (AI) techniques. These learn from user actions and predict their next moves. Direct manipulation interfaces aim to put the user in total control. Both approaches have their benefits and many interfaces combine aspects of both worlds. For this design I decided to follow the latter.

In one of his papers Ben Shneiderman (1997) introduces three key principles to define direct manipulation UI design:

1. Continuous representation of the objects and actions of interest;
2. Physical actions or presses of labeled buttons instead of complex syntax;
3. Rapid incremental reversible operations whose effect on the object of interest is immediately visible

Shneiderman says that by following these principles it is possible to design systems that have several beneficial attributes including good learnability, efficient workflow, less user anxiety and increased feeling of mastery. Many of these benefits stem from the basic idea that the representation of the user interface is very close to the user's internal vision of the high-level task.

In addition, direct manipulation contributes nicely to solving the problems with user motivation from the previous chapter. For instance the motivating factor of challenge and control can be achieved with well-planned direct manipulation. Also user choice is emphasized more than with autonomous agents.

### *Affordances and design rules*

Perception theorist J.J. Gibson introduced his concept of affordance theory around the end of 1980's. This theory had a big impact on the way we think about perception. Instead of a prevailing atomistic no-

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<sup>13</sup> <http://en.wikipedia.org/wiki/Skeuomorph>

tion of analyzing perception in a bottom-up manner starting from rays of light, Gibson claimed that we perceive in order to operate in the world. Although problematic if taken too literally, Gibson's theory is very welcome for information visualization and interface design where the key question is how to guide action (Ware 2000).

In interface design Gibson's affordances can be used to give us tips on how a system is operated. For instance in the physical world a door handle communicates that it is hand-operated by using a variety of hints, such as placement height, size and material form. In digital interface design such hints can be given with elements like graphical symbols, animations or interface structure.

Another proponent on the use of affordances is Donald Norman. In his book "The Design of Future Things" he writes down six rules of design. Although the book emphasizes more the design of autonomous agents, the rules can be applied to any interface design (Norman 2007):

1. Provide rich, complex, and natural signals
2. Be predictable
3. Provide a good conceptual model
4. Make the output understandable
5. Provide continual awareness, without annoyance
6. Exploit natural mappings to make interaction understandable and effective

Following these rules fortifies the user's feeling of being in control, but in comparison to Shneiderman's direct manipulation principles they also allow some leeway for autonomous agents as long as these agents support rule number five.

### *3.3 User interface design*

The effect of Shneiderman's direct manipulation principles can already be seen with the central piece of the user interface: the 8 by 8 panel element. Touching on the element draws in real time showing the end result both on the user interface as well as on the panel. Picking the active color happens like on a palette by touching the desired color above the panel element. The main navigation is shown on the top of the user interface.

Before actual implementation, the first concrete steps in design were taken with paper and pen. Once enough iterations were played with this medium the implementation started as HTML-pages. At first the UI only included live drawing, but later animation support and text writing were added. This required restructuring the view hierarchy.



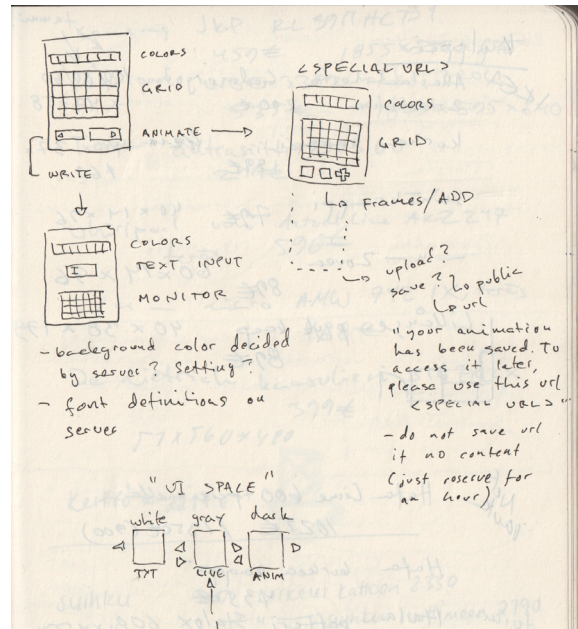
After another set of paper sketches the design was transformed into HTML pages again.

The interface is designed with a focus on touch interaction. This means that elements need to be big enough and keyboard shortcuts along with mouse right-clicks can't be used. The user interface scales according to the screen size and thus can be used on smaller mobile phones and tablets alike. Although the touch experience is placed first, all the features also work on normal desktops with keyboard and mouse.

The UI went through three major iterations from the first working prototype to the version 1 and then to version 2. During user testing both of these versions were tested and the feedback guided the plans for the upcoming version 3, which is discussed at the end of this chapter.

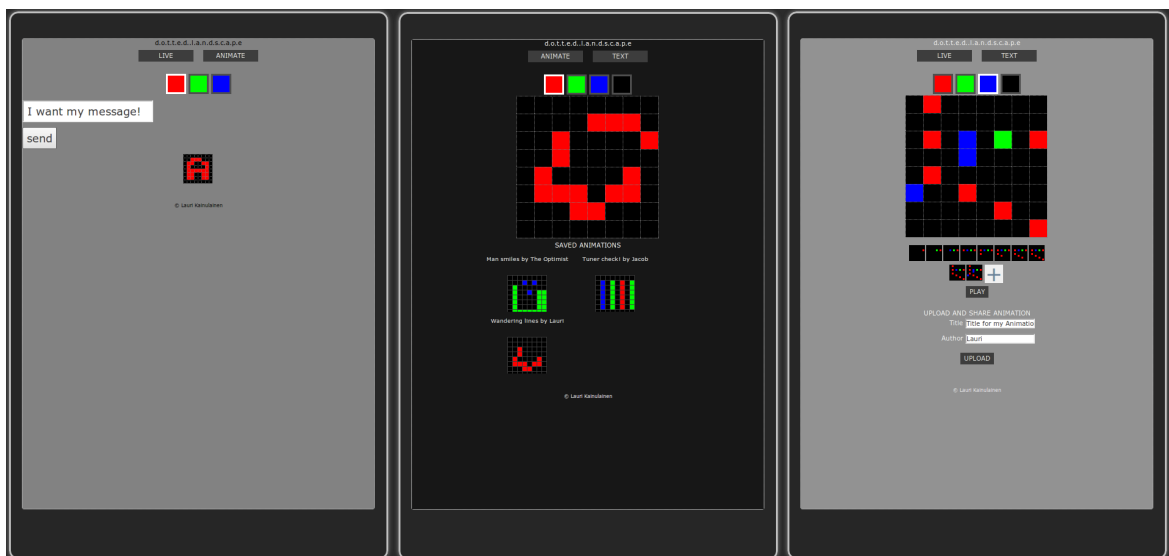
### *The three views of the user interface*

The user interface has three views: live drawing, animation editor and message sender. The first page to open is the live drawing where the user can directly paint on the panel. Here the user is presented with an 8 by 8 grid that reflects the current status of the light panel. Touching or clicking the grid sends a draw command on to the server and the change notification from the server makes the user interface element update its state.



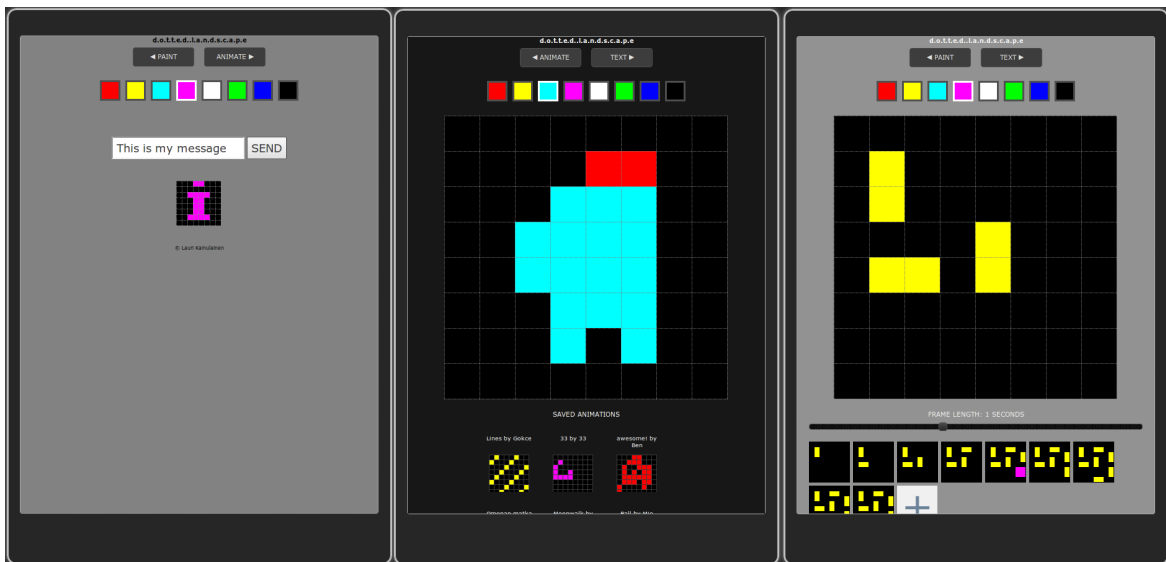
**Image13: Sketches of the user interface from September 2011.**

**Image14: Three views of the user interface: message sending, live drawing and animation editor (version 1). Taken from an iPad emulator.**



The message sender view presents the user with a simple text input field and a send button. The messages sent through this view are instantly played on the panel. A small panel overview is present in the lower portion of the page to see what is going on in the panel during the drawing.

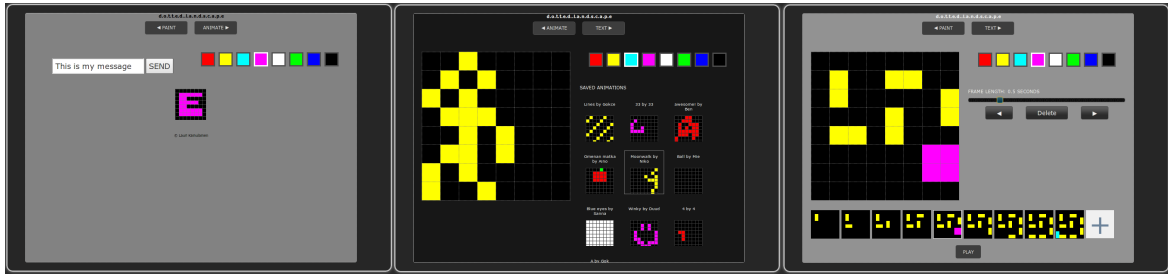
The animation editor is the most complex part of the UI. Through this view the user is able to create animations by drawing one frame at a time. Version 2 also included support for deleting frames, editing them, changing frame duration and rearranging their order. All actions only happen locally so creating an animation does not intervene with live drawing or messaging. A submission form is included at bottom of the page to upload the animation to the server. After this they can be played through the live painting view.



**Image15: All three views of the user interface version 2 in portrait mode.**

Since the web application might be viewed through various different devices with different capabilities and screen sizes, the design of the user interface needs to be fluid so that an optimal view can be presented. This is often called Responsive design in web development. CSS Media-queries<sup>14</sup> were used in version 2 to supply a different layout for bigger screens by enlarging parts of the user interface to better use the screen estate. Also a separate layout was designed for devices that were used in landscape mode instead of the default portrait orientation. The functionality of the layouts was kept identical. The images below illustrate the way the UI in version 2 reacts when the orientation of the device is landscape.

<sup>14</sup> <http://www.w3.org/TR/css3-mediaqueries/>



**Image16: Three views of the UI version 2 turned to landscape mode.**

A key question in designing the user interface was the representation of the light panel. In order to follow the rules of direct manipulation, the interface element should closely match the real world object. The end result is an 8x8 matrix where each of the cells in the matrix represent one light sink in the panel. Pressing a cell applies the currently active color to that cell. A key question here was the size of the cells in the panel element. How small could they be while still remaining usable on a small touchscreen, such as those provided by modern smart phones.

To form a general idea of what sizes are good on current mobile devices I turned to look for the recommendations of phone UI toolkit developers. To remain independent of the platform I chose to look for an average recommendation. Luke Wroblewski provides a quick overview of the minimum touch target sizes defined by the manufacturers (Wroblewski 2010):

- Microsoft recommends a size of 9mm/34px and sets the minimum at 7mm/26px.
- Nokia recommends that the touchable elements should be larger than the average finger pad, which is 1cm in diameter. Minimum sizes are 7 x 7mm with 1mm gaps for the index finger and 8 x 8mm with 2mm gaps for thumbs.
- Apple says the minimum size of a touch target should be 44 pixels wide 44 pixels tall (for 1st generation iPhone). This translates to 6.9mm.
- Ubuntu Finger UI Human Interface Guidelines (HIG) state the minimum size of buttons and other elements to be determined by the adult finger size, which according to them is between 16 and 20mm as users prefer to use the pad of their fingers instead of the very tip. In general the guideline states that the element should not be smaller than 10mm.

A study at MIT Touch Lab also concludes the average human index finger width to be from 16 to 20 millimeters for most adults (Dandekar et al. 2003). The interface target size doesn't always need to be as large since the tip of the finger suffices for interaction.

Looking at these results it seems that a size of 1 centimeter is a good bet as a minimum value for smaller devices. However on larger devices, more screen estate can be used. That is why version 2 provides a user interface with 2x2cm cells for devices such as tablets that have a pixel width of 768 or more.

### *Plans for the user interface in version 3*

The focus for version 3 is more emphasis on animations and support for communal activities. This will be realized in the form of commenting and up-voting on animations. The functionality is placed on a specific page created for each animation. A user must wait 30 seconds to post another comment or vote again. This is meant to somewhat protect the system from flooding or scripted voting, while still retaining the possibility to act anonymously on a shared device. To allow better support for follow-up actions and provide value for the animations in the future, the individual animation page will also feature a button to download the work as an animated GIF-image.

Another communal feature is displaying the amount of active users as a visual icon and sum. This will hopefully help to create an online honey-pot effect which, as described in Chapter 2, is important for attracting users. Collaboration aspects are also considered by adding a feature that allows users to identify the person behind each live change in the panel. This is achieved by giving each connected user a unique color, which is quickly flashed as a small spot over a colored panel pixel. This makes it possible to follow the live drawing actions of one person even when there are several people connected. As described in Chapter 2, this viewing of one's actions has an increasing effect on motivation.

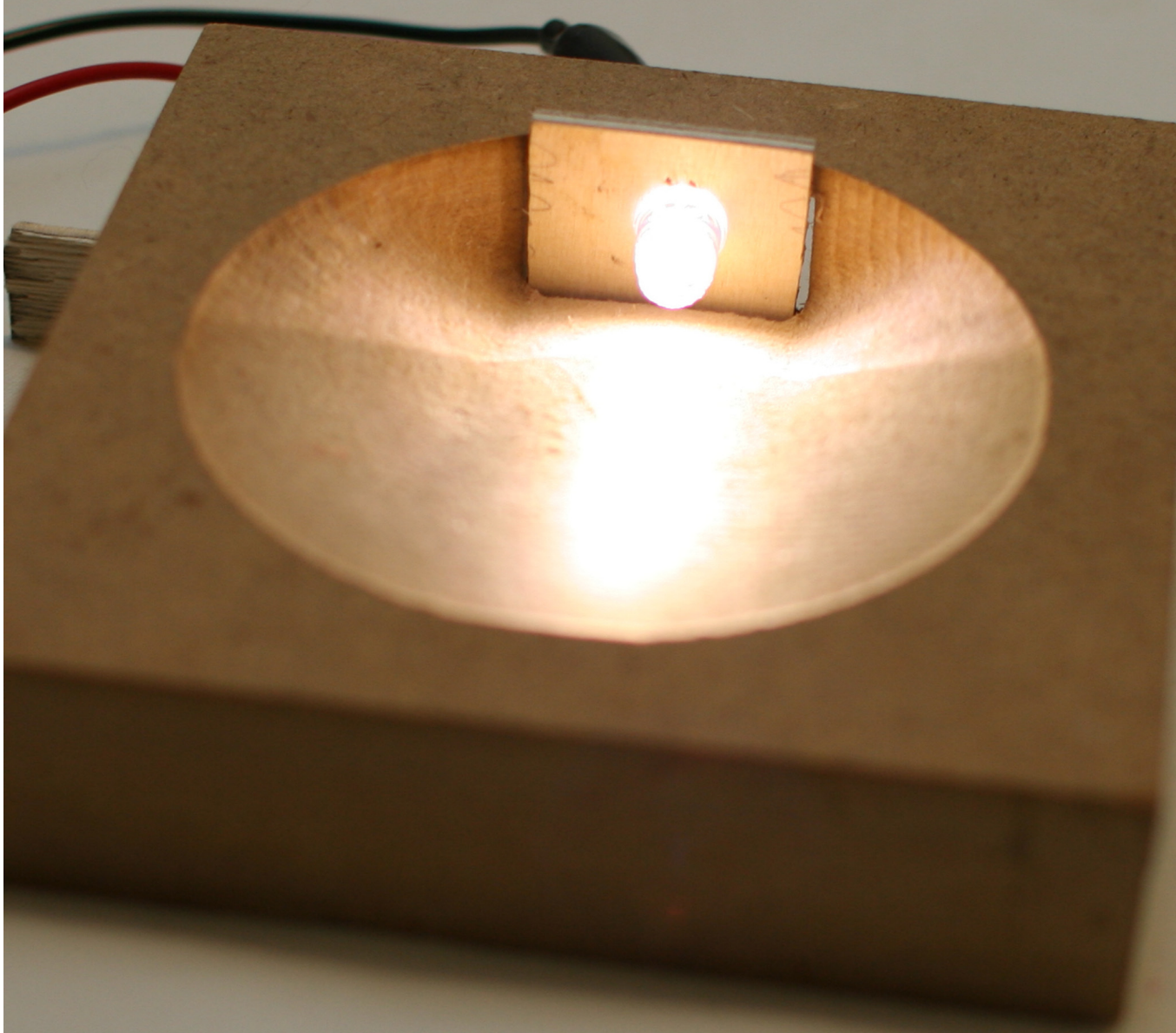
Statistics will be gathered on all actions happening in the user interface. This includes play counts for animations, sent messages, drawn colors, etc.. An idle player will be added to run visualizations while nobody is interacting with the piece. General changes in the interface include moving to the direction of a pure web application, where the address bar is hidden and the user experience feels more like a native application. This will be done with the help of jQuery Mobile<sup>15</sup>. In addition typography will be updated to a selected embedded font to increase visual appeal, enforce identity and improve readability.

Issues discovered during user testing will be fixed. For instance the navigation on top will be changed to a consistent three-item menu to help with some of the navigational problems encountered. Also troublesome user interface elements, such as the frame duration slider, will be redesigned.

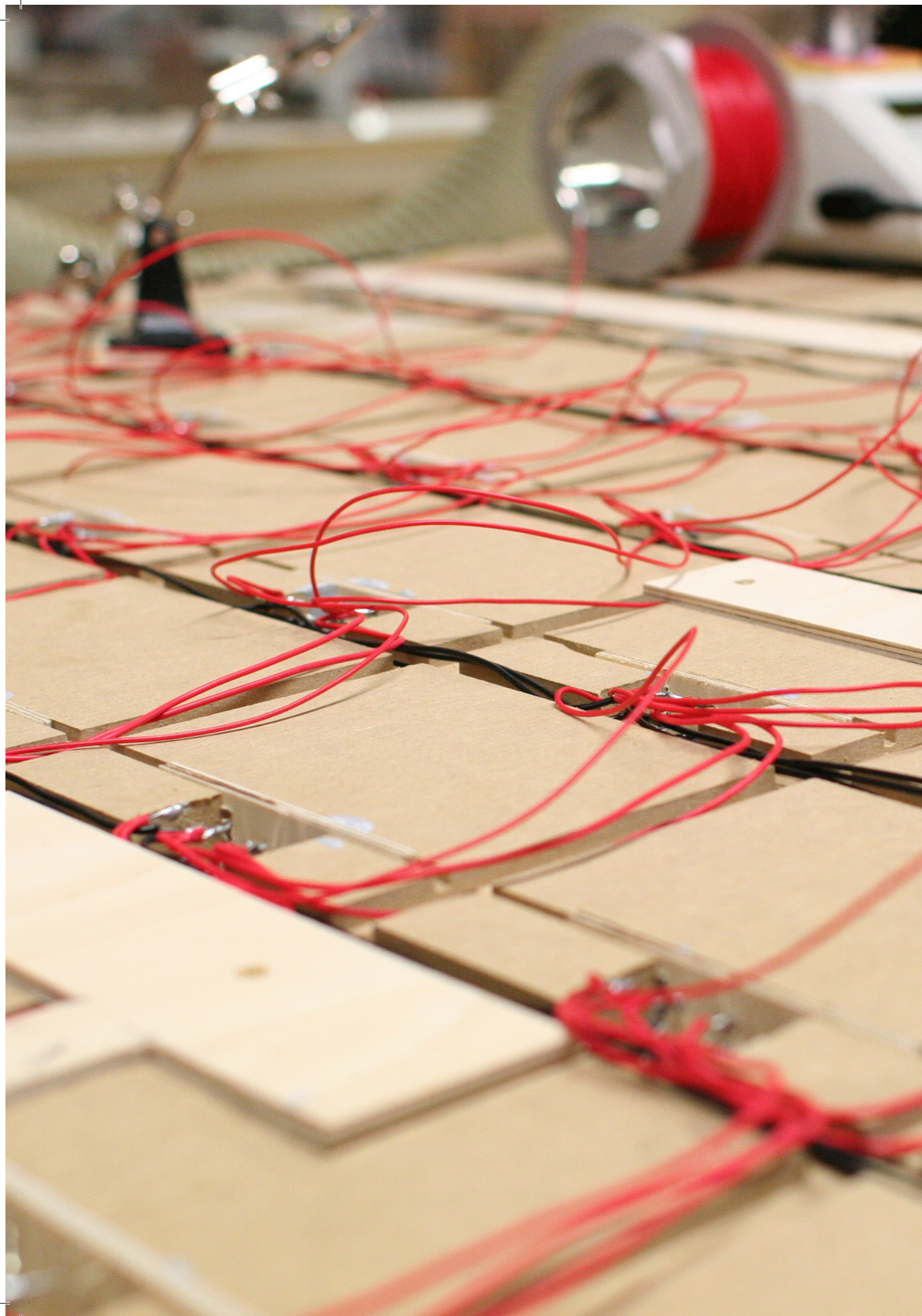
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<sup>15</sup> <http://jquerymobile.com/>









## 4 Creating the internals: electronics and software design

Dotted Landscape features some fairly advanced programming. The core of the service is a small server that keeps up the panel state. The web application is served with the help of another server. On the electronics side I use MAX7219CNG<sup>16</sup> chips to drive the array of 192 LEDs with an Arduino<sup>17</sup> board controlling them.

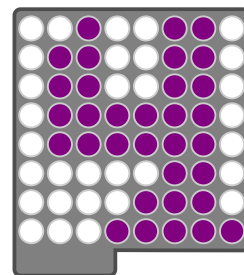
In this Chapter I will dive into more depth about the software and hardware used to run Dotted Landscape. In addition to the technical concepts I will also explain the design drivers and overall process. I will begin with software and then proceed to hardware. Plans for version 3 are discussed in the end. The description here will remain on a high level. More low level explanations such as classes and component structure can be found from the source code.

All software code and microchip logic, including static assets such as fonts and images, is available in the project repository at <https://github.com/luopio/dottedlandscape>. The code is licensed under a very permissive MIT license<sup>18</sup> that allows unlimited re-use, modifying and even selling of the software.

### 4.0 Software Design

At the heart of Dotted Landscape is a small server. This panel server only knows the current status of a rectangular matrix and its task is to draw on it and notify all connected components when it changes. Another server provides the web front end and relays drawing commands to the panel server. A third process runs the serial connection relaying commands to the electronics while listening to the current panel state from the panel server.

The Blinkenlights project introduced in the related works section provides their software as open source. This makes it easy to download the code and go through their solutions. Considering that they have several years of experience in building these interactive light installations I decided to start my development by looking through their work. Eventually I implemented support for the Blip-protocol that they use to relay their draw commands. This allows Dotted Landscape to play content used in the Blinkenlights project, giving me a great way to test my own server with client applications provided by them.



16 <http://www.maxim-ic.com/datasheet/index.mvp/id/1339>

17 <http://arduino.cc/en/Main/arduinoBoardUno>

18 <http://www.opensource.org/licenses/mit-license.html>



Also additional features such as the possibility to play GIF-animations are supported through the Blinkenlights player.

### *High-level architecture*

The software components are organized in a flexible three-tier architecture. This architecture is a common variation of the N-tier model and frequently used with web applications. The three tiers in the architecture are often called *presentation*, *application* and *data* tier. The idea is that the presentation tier never talks directly to the data tier. Instead communication cascades through the tiers between them.

Three-tier architectures are often easy to extend because a component on one tier can be separated and exchanged for another. My design was partly driven by imaginary scenarios where the light panel would be driven by motion sensors directly without a web interface, or alternative hardware designs where the matrix form was broken into a bunch of lights lying scattered on a level surface. These kinds of scenarios are possible by just building new tiers to reflect the changes in the usage scope.

The panel server is also relatively agnostic to the purpose of the data it manages. Anything that can be represented as an array of numbers from 0-255 can be transmitted through the server and small modifications to the protocol could easily extend the support to fraction numbers or text. The size of the managed data array is determined when the first update from a client is received.

**Illustration7:**  
**The three-tier**  
**architecture**  
**and connections**  
**between the**  
**central**  
**components.**

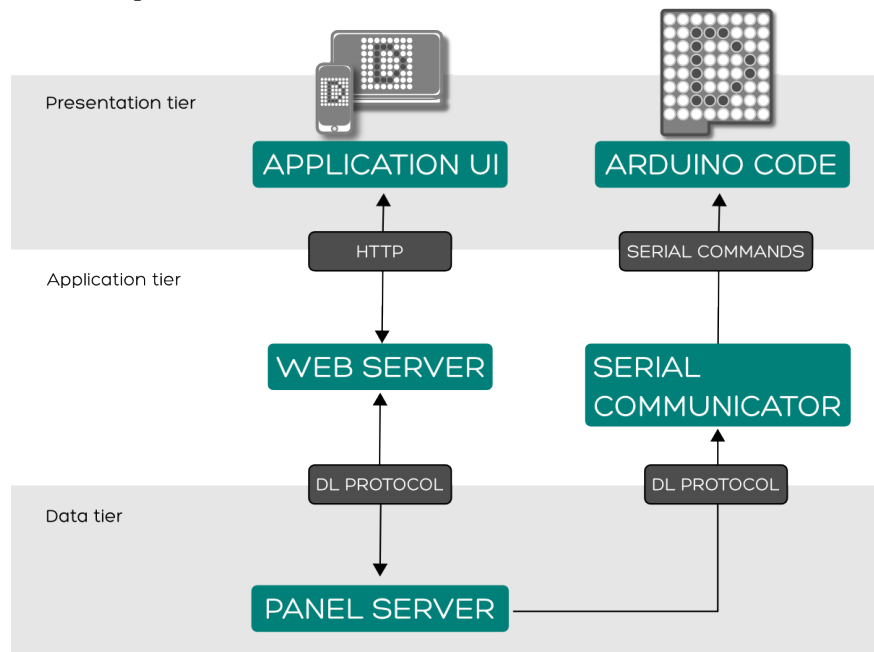


Illustration 7 shows a high-level view of the software components. The web application user interface as well as the microchip code

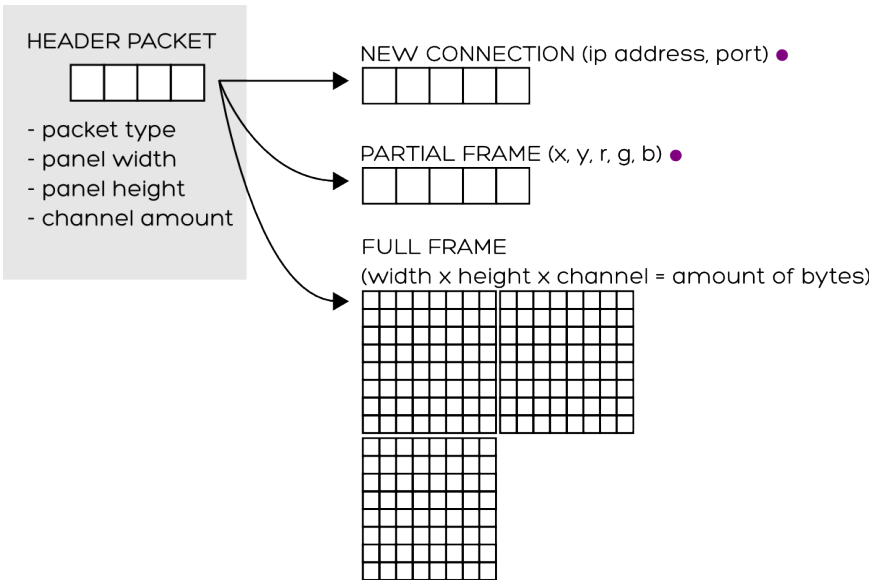


working inside the Arduino microcontroller can be thought of as the presentation layer in the three-tier architecture. These communicate with an underlying application tier component. In the case of the web application this is the web server which is reached through the Hypertext Transfer Protocol (HTTP). The web server and the serial communicator components run in their own processes and communicate with the client through the Dotted Landscape protocol – an extension of the Blip-protocol. The panel server on the data tier reacts to commands and sends updates to all listening clients. Clients are not forced to communicate anything after initial connection. For instance the serial communicator only listens for update notifications without affecting the panel status at all. Also some clients, such as the Blip-protocol testing client, only send updates to the server without listening to what happens.

*Component communication*

Three different protocols are used by the components. Between the presentation tier and the application tier the communication method is dictated by the standard capabilities of the software environment. In the case of the web server communication happens through HTTP. For the Arduino, the serial communicator uses the serial port to send a packet containing the frame to be displayed.

The Dotted Landscape protocol used between the application and data tiers is an extension of the Blinkenlights Blip-protocol. To transport its commands it uses User Datagram Protocol (UDP), which is common in server-client architectures where performance is more important than absolute data integrity. Illustration 8 summarizes the three types of packages used by the protocol.



**Illustration8:**  
**Dotted Landscape**  
**protocol handles**  
**three types of**  
**packages. The first**  
**two are extensions**  
**to the Blinken-**  
**lights Blip-protocol**  
**and marked with a**  
**purple circle.**

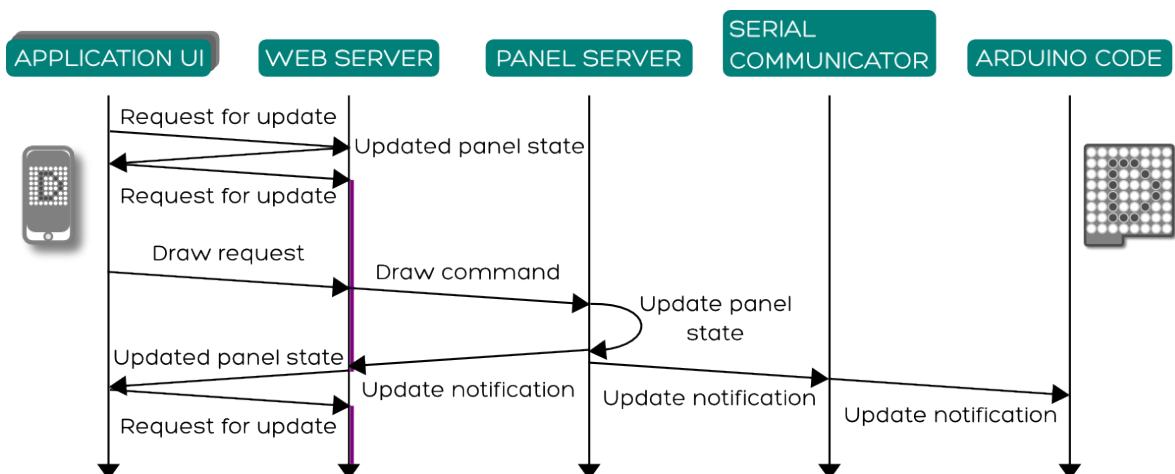
The communication is usually initiated with a new connection packet send by a client. The client needs to give its address and port to the server so that update notifications can be sent. New clients can join at any time. If clients only wish to post updates they can just send full frames directly without handshaking with the server.

The drawing happens either with full frames being sent according to the Blip-protocol or by sending changed pixels through the partial frame packet. The latter is an extension to the original protocol that makes it much more cheaper to send client events from the web server. Especially when there are several clients connected. The server itself does not define the panel size. Instead the panel size is defined once the first draw command is sent. This makes the server implementation more general and less reliant on the actual usage context.

The panel server only sends packets that contain the full frame data. This has two advantages: clients can't be out of sync as they always receive the full frame and the server remains completely compatible with the Blip-protocol. This means that the panel server could be used to connect the web functionality of Dotted Landscape with the huge visualization systems of the Blinkenlights project.

The communication method between the web application and the panel server follows an observer software design pattern where the panel displayed on the user interface won't update until the server sends an update notification. This is a fairly common method and ensures that the user interface state is in sync with the panel server. The alternative would be to update the user interface as soon as the user touches a panel cell and then send a draw command to the server. However doing this could lead to serious inconsistencies and make it more difficult to implement synchronous, collaborative drawing that is now possible. This kind of communication method where the data layer needs to notify the interface layer before any noticeable change

**Illustration9:**  
**Communication**  
**order between the**  
**system entities.**  
**The purple lines**  
**signify the lifetime**  
**of the long-polling**  
**web application**  
**requests.**



is presented is often associated with the Model-View-Controller architecture (MVC). For more explanation on MVC see Enode (2002). The need to be updated by the server makes it possible that dozens of browsers can be viewing and drawing on the site simultaneously and see what others have drawn in real time.

Illustration 9 depicts the communication between the system components. Due to the nature of the HTTP, connections must be initiated from the client. This is why the interaction begins with a request for update from the web application. As this is the first connection, the web server answers immediately with the current panel state. This makes the application UI update its view and issue another request. This request hangs until the panel state actually changes. A draw command from the client causes the web server to notify the panel server. This carries out the needed changes to the panel state and sends the current full frame to all listening clients. At this point the web server returns all waiting update requests by supplying the current panel state.

The long-polling solution between the application UI and the web server is still fairly unorthodox in modern web development. Due to the near real-time communication requirements in Dotted Landscape it is needed, as the alternative – continuous HTTP polling – would be very slow. For a more elaborate description on long-polling and asynchronous web servers in general see Carbou's article (2011).

### *Selecting the software components*

Most of of Dotted Landscape – including all the servers – is implemented using the Python programming language<sup>19</sup>. Python was chosen due to its familiarity to me as well as its flexibility and selection of libraries. Underneath the hood the panel drawing server is implemented using a library called Gevent<sup>20</sup>. This library allows me to evade using threads – a common way of separating one branch of a program to run on its own. Although very useful and simple in principle, the concurrency achieved through threads usually causes problems even for experienced programmers. Common error scenarios include moments where two threads read and write to the same variable corrupting memory and causing so called race-conditions – problems that are very hard to debug. Gevent allows concurrency through co-routines. These small units of execution provide the chance to release control from one part of the program to another. A scheduler run by Gevent sees which co-routine needs to execute next and allows it to do its work until it releases control again. There are no race-conditions as all the routines run cleanly one after another and no real loss in performance compared to threads.

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<sup>19</sup> <http://www.python.org/>

<sup>20</sup> <http://www.gevent.org/>

The web server has been implemented in Tornado<sup>21</sup>, a fast asynchronous server that powers services such as Facebook's Friendfeed. Tornado covers the need for long-polling HTTP-queries which make the near real-time updates possible. The application user interface served by Tornado is implemented in standard HTML5. Interactivity is brought through Javascript with the help of the jQuery<sup>22</sup> library.

A separate small testing client was created with PyGame<sup>23</sup> – a Python-based cross- platform game development library. The client connects directly to the panel drawing server using the Dotted Landscape protocol and draws the panel state whenever it changes. This made it easier to test the panel drawing functionality without first needing to build the web interface. Also simple stress testing was possible by opening dozens of panels simultaneously and then drawing through the web interface.

The functionality for animations has been encapsulated under the web server. This means that timing of frames, saving the animation to a Redis<sup>24</sup>-database and playing a selected piece are all handled by the web server in a separate thread. The decision to place the functionality under the web server was made to keep the actual panel server lighter. Also the animation functionality is only used by the web application and moving it to a lower tier would over-complicate the communication between the panel and web server.

## *4.1 Building the electronics*

Driving one LED is easy: you give it around 3 volts and it lights up. Driving the 192 LEDs in Dotted Landscape introduce the challenge of controlling them individually. For simple LED works that feature around 10 LEDs it is possible to directly use output connections in a microcontroller such as the Arduino Uno. However the output connections in a basic microcontroller are usually limited to around 20.

A common solution to increase the amount of controllable LEDs is to connect them in a matrix where all LEDs on one row are connected through their cathode and all LEDs on one column are connected through their anode. Then by applying a technique called multiplexing the voltage on one row is pulled down while others remain up. This causes LEDs on that row to lit up if the corresponding columns have enough positive voltage to generate a high enough potential difference – in the case of these LEDs around 3 volts. A few microseconds later the same procedure is repeated for the next row. In multiplexing

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21 <http://www.tornadoweb.org/>

22 <http://jquery.com/>

23 <http://www.pygame.org/news.html>

24 <http://redis.io/>



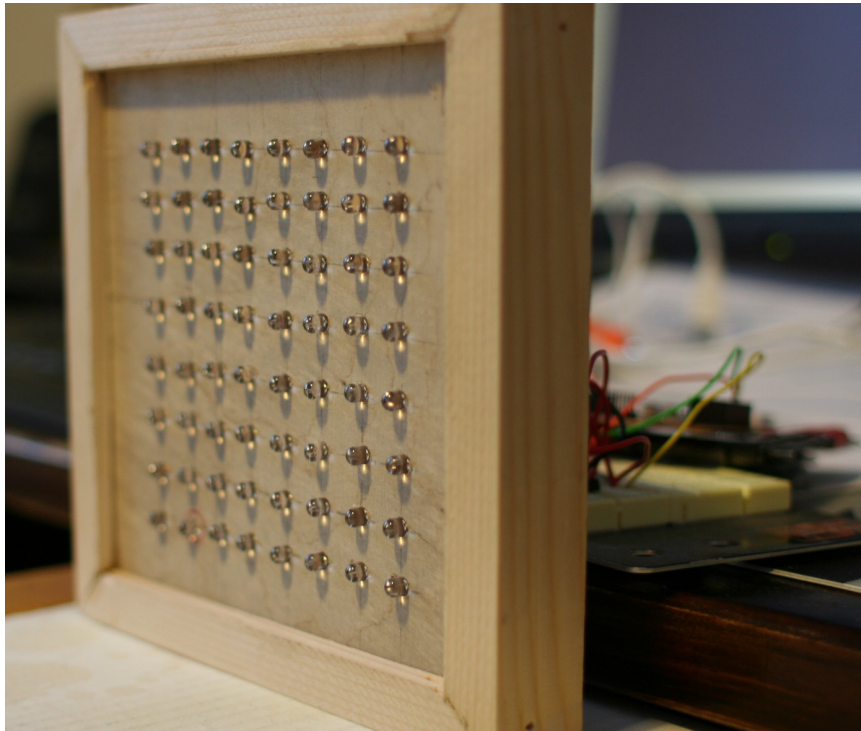
the rows are lit so fast in succession that it is impossible to detect the difference between the blinks. This makes the maximum power consumption of the whole panel equal to the consumption of one row of LEDs being all lit at once. However, even with this technique it would be impossible to control 192 LEDs with just the microcontroller.

The solution in Dotted Landscape is to use three LED driver chips. These chips are a fairly common solution to abstract the multiplexing and control logic of the individual LEDs. The driver chips are MAX7219 from Maxim (Maxim 2010). One chip is able to drive a maximum of 64 LEDs and requires just three connection pins from the microcontroller. A combination of three chips was needed to create separate color channels for red, green and blue.

### *First step: building a prototype panel*

A prototype was built first to validate the technological choices and provide the possibility to write the microcontroller code without the final hardware setup. The prototype panel was built using one MAX7219 chip combined with an Arduino compatible Seeduino board and 64 5mm red LEDs.

Building was fairly straightforward with instructions available in the Arduino Playground (2012). The process took only a day for the hardware and two more to build a preliminary serial interface between the microcontroller and the server software.



**Image17:**  
**Prototype panel.**

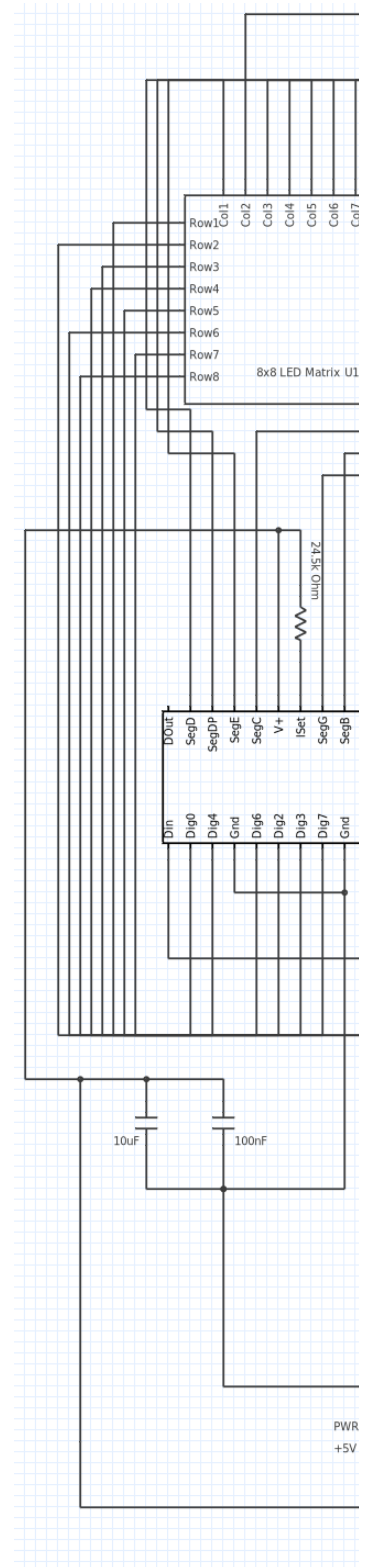
## Schematics of the final work

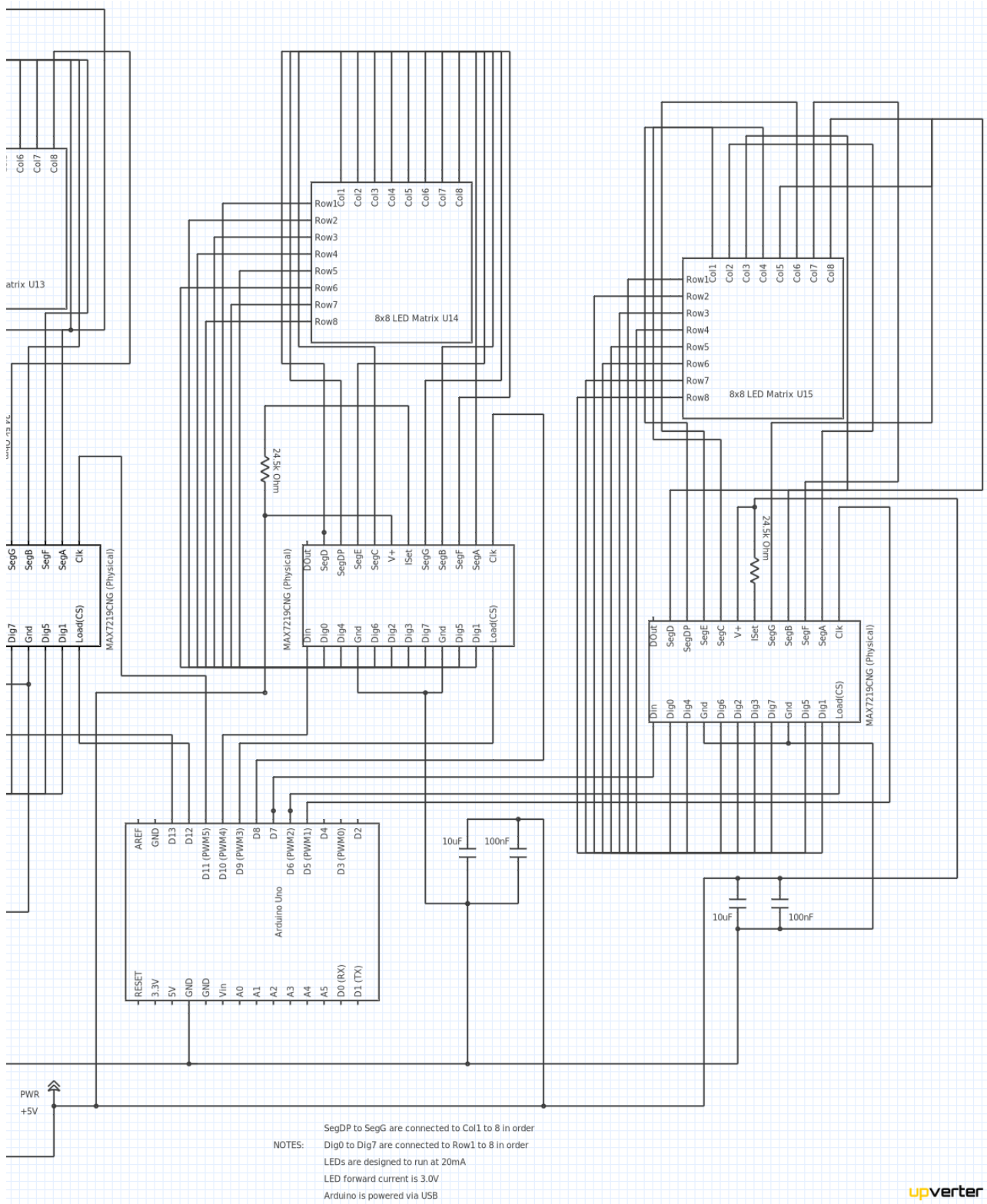
The final production combines three MAX7219 chips to control three channels of colors. One Arduino microcontroller drives the chips and a serial connection via the USB port of the computer sends commands to the microcontroller. Some resistors and capacitors are also included to control the voltage and minimize the power fluctuations. Each LED driver uses three output pins from the Arduino and they share the same connection to ground and 5V voltage.

The schematic below shows the design in more detail. This schematic was created through Upverter.com – an online sharing and creation tool for electronic diagrams. The schematic is shared with a liberal Creative Commons license to enable others to use and build upon it. The more detailed and editable version is available online at <http://upverter.com/luopio/1970dc094eec1a93/Dotted-Landscape/>.

To draw the schematic I needed to include two electronic components to Upverter: a generic LED matrix and the MAX7219CNG chip used to drive the LEDs. A previous version of the chip existed, but it did not have the connection pins in the physical order. I wanted to have the connections represent the actual physical order so that the schematic would be more useful as a validation tool during the actual building phase.

As a first experience Upverter proved out to be quite easy to use. However already with the kind of complexity Dotted Landscape introduced, the diagram started becoming messy with Upverter's own connection routing algorithm. On hindsight, I would not recommend Upverter for larger projects at this stage. Some of the tools I was expecting, like voltage calculations and error spotting are not there yet. For future reference I will be resorting to more complicated professional software such as Eagle<sup>25</sup>, which is also available for free.





**Illustration10: The schematics of the electronics setup.**

## 4.2 Plans for version 3

The performance of version 2 was fairly good. However the situation may worsen when there are several users connected to the web server under bad network conditions. To overcome these issues the HTTP communication will be replaced with Socket.IO<sup>26</sup>. Socket.IO is a server and client component that allows capable clients, such as newer web browsers, to employ socket connections instead of HTTP requests. Socket connections don't have to close between update notifications making them much more faster. A server component called TornadoIO<sup>27</sup> will be used bring Socket.IO support to the existing web server.

An idle player component will be introduced. This component tracks if the panel has any active users and if not, it starts playing content such as saved animations or generative content like the Game of life<sup>28</sup>. This ensures that the panel won't just freeze without active usage.

Occasionally, when flooded with draw commands, the serial connection between the Arduino and the serial communicator transmits faulty packets that create graphical glitches on the light panel. These issues are already being addressed by a static checksum in the communication, but for version 3 this checksum will be modified so that each packet carries a number that matches the combined values of all its pixels. This hopefully minimizes the unwanted flicker.

For version 3 the code will be refactored slightly to be more easily understandable. General structure will be kept and all the key components will remain in places. Mostly some embedded functionality, such as the animations inside the web server, will be separated to their own own classes. Inline documentation inside the source code will be improved and general instructions for running and building the software will be added.

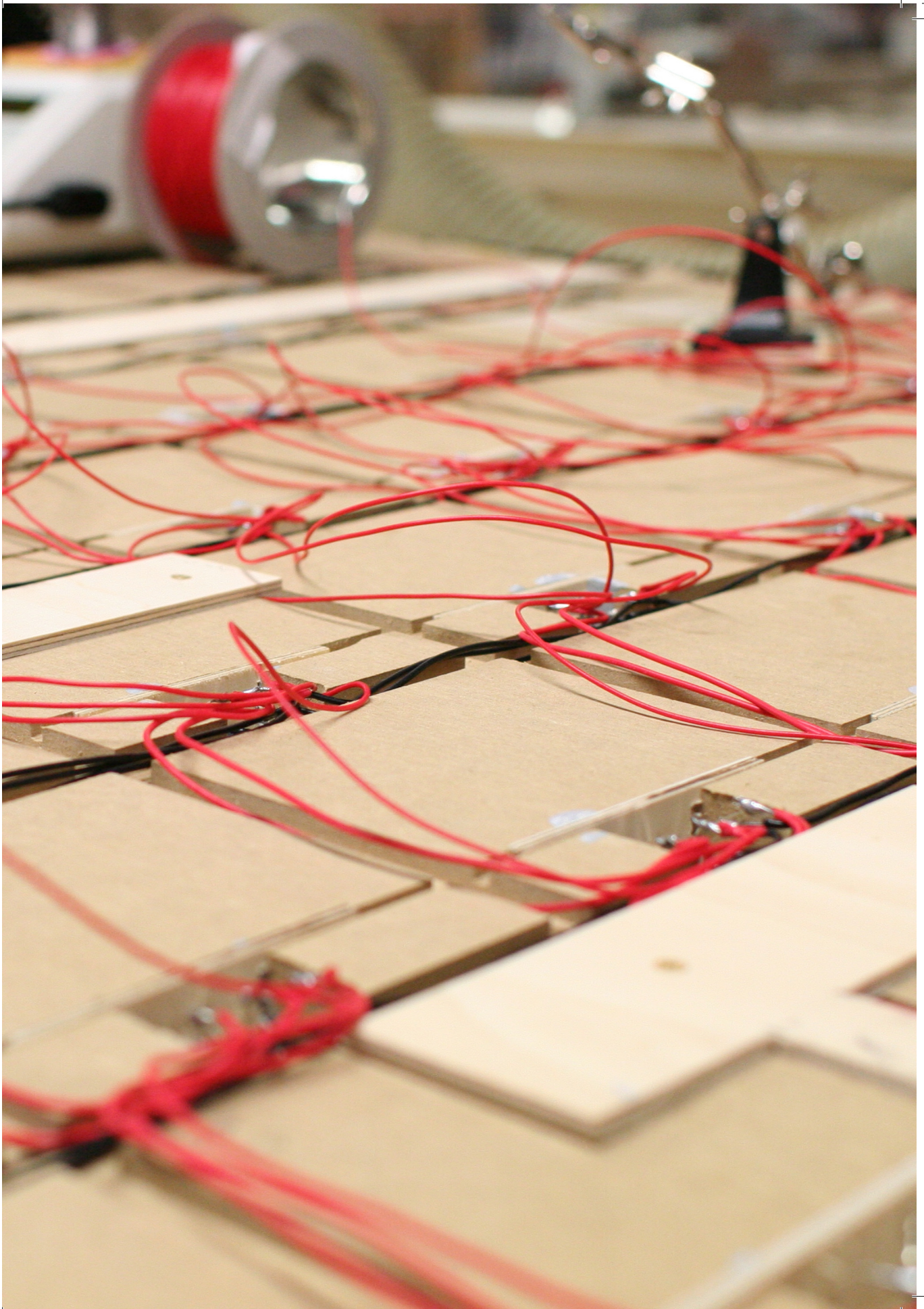
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<sup>26</sup> <http://socket.io/>

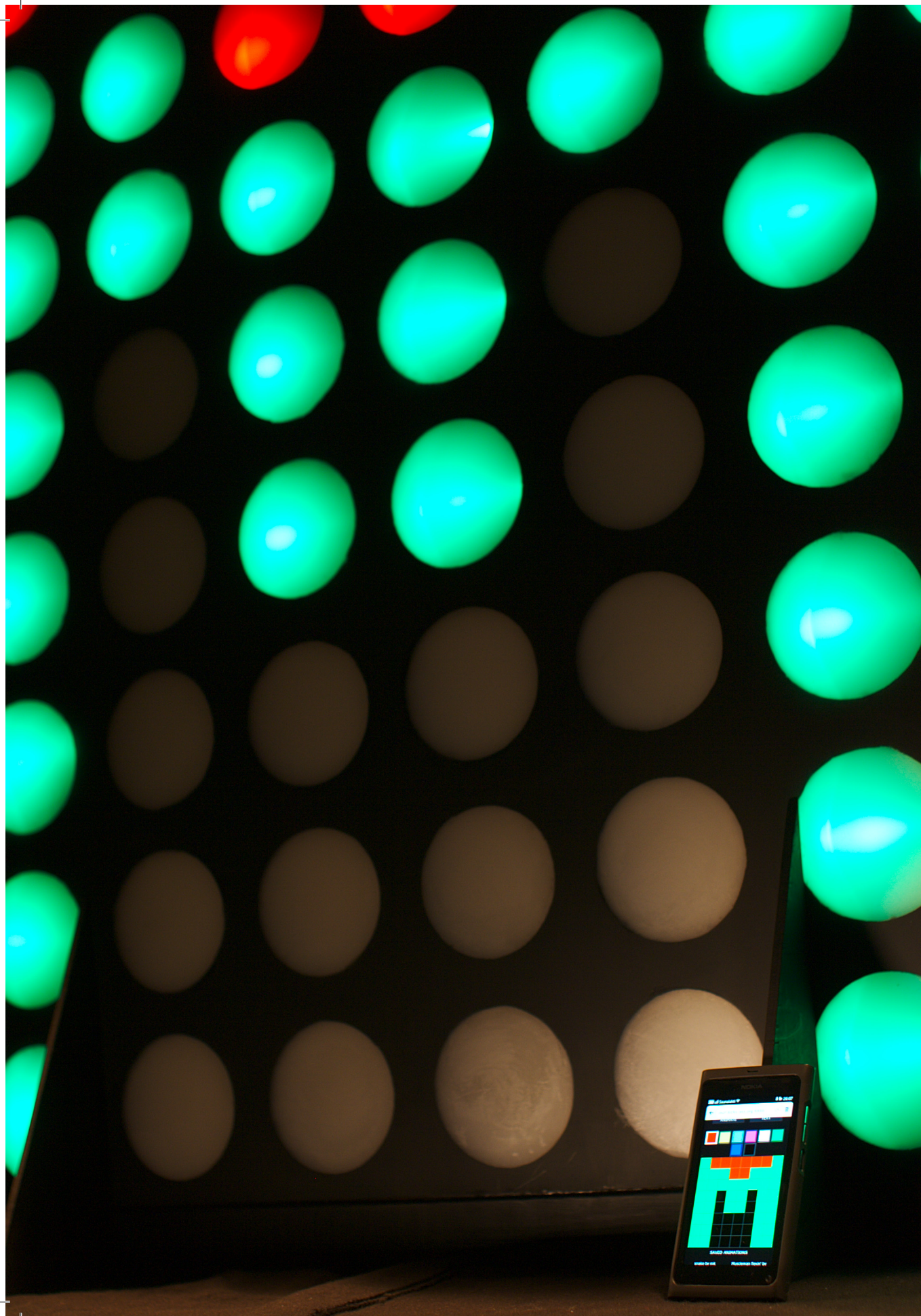
<sup>27</sup> <https://github.com/MrJoes/tornadio2>

<sup>28</sup> [http://en.wikipedia.org/wiki/Conway%27s\\_Game\\_of\\_Life](http://en.wikipedia.org/wiki/Conway%27s_Game_of_Life)









## 5 User testing

First deployment of Dotted Landscape was organized in the Medialab of Aalto University. The light panel was placed in a small studio and seven user tests were carried out. The participants were given a mobile device and they followed a list of tasks to complete with the web application. After this they filled a short questionnaire and some discussion ensued about their experience. Although seven people do not represent a very large population, this amount should be enough to spot around 80% of the issues and give a good idea on what people think about the panel (Nielsen 2000).

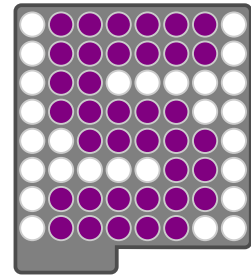
Several issues were discovered during the testing. In addition to a handful of plain bugs in the user interface logic, 6 out of 7 users had problems with the fact that not all functionality fitted on one screen. This was very evident in the animation screen, where the play button was hidden until scrolled down. Other issues included the lag experienced while drawing, understanding the slider for adjusting the frame duration and the separation between the different views in the user interface.

In this chapter I will first explain the user testing setup and then proceed to explain the results in more detail. The list of answers is not enclosed because it would be very easy to single out who said what and permission for this was not requested from the participants.

### 5.0 Test setup

The experiments were carried out in regular usability testing manner: the participants worked on their own and I monitored their progress. Help was only given when the participant got stuck on a task for a very long time or to prevent the participant from doing something drastic, like leaving the animation editor before saving her work. Throughout the experiment the participants were asked to think out loud.

I knew all of the participants from before so some bias can be expected in the results. However it seems that most – if not all – participants were honest in their opinions. All participants were highly educated with two coming from an engineering background, one from the public relations field and others working in new media. One participant was a professional animator.





## *Tasks to complete*

Following is the list of assignments that the participants were asked to perform. The intent was to target the three main sections of the user interface and test the majority of the features implemented in version 1.

1. The tasks to complete were the following:

1. Draw a stick figure on the panel
2. Erase the legs of the stick figure
3. Change color to green and draw the stick figure new pants
4. Paint the area behind the stick figure blue
5. Create a new animation, use the stick figure or whatever content you wish
6. Play the animation in your device
7. Save the animation
8. Play the animation on the panel
9. Send a text message on the panel. Use the phrase “Hello world” or whatever you wish.
10. Draw a smily face.

## *Questionnaire structure*

In order to gather a set of more quantifiable data the participants were asked to fill out a questionnaire. The questionnaire was created in Google Docs<sup>29</sup> and had three sections with the following content:

1. User interface and external form
  1. Understanding how the user interface works was...  
(scale of 1 (Difficult) to 5 (Easy))
  2. Live drawing on the panel was...  
(scale of 1 (Difficult) to 5 (Easy))
  3. Creating animations was...  
(scale of 1 (Difficult) to 5 (Easy))
  4. Sending text messages was...  
(scale of 1 (Difficult) to 5 (Easy))
  5. I feel that the external form of the panel is...  
(scale of 1 (Ugly) to 5 (Beautiful))
  6. I feel that the external form of the panel is...  
(scale of 1 (Dull) to 5 (Inspiring))
  7. Live drawing on the panel was...  
(scale of 1 (Not enjoyable) to 5 (Enjoyable))
  8. Creating animations on the panel was...  
(scale of 1 (Not enjoyable) to 5 (Enjoyable))
  9. Sending text messages on the panel was...  
(scale of 1 (Not enjoyable) to 5 (Enjoyable))

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<sup>29</sup> <https://docs.google.com>



## 2. Panel usage

1. Please select TWO features that are most important for you (*options of: Creating animations, Drawing in real time, Writing text messages, Commenting on animations of others*)
  2. Please select maximum of THREE locations that you think would be most suitable for the panel (*options of Cafe, Public space, Hotel lobby, Private home, Museum, Night club, Other: <free text>*)
  3. Did you miss any features? Any other usage scenarios you would have liked to see? (*free text*)
  4. For me the possibility to interact with the panel was... (*scale of 1 (Not important) to 5 (Very important)*)
3. Any other comments, ideas, critique? (*free text*)

The questionnaire is still available online in the URL <https://docs.google.com/spreadsheets/viewform?formkey=dFdRYnVzR1cz-NlZwQzFkcThnbnJEanc6MQ&theme=oAX4zCRMsmRFbUy1lNW RkZjhlYyoxMWZILTQzZmMtOGIzOCoyNzRlNGEwOGViZmU&fq> (Accessed 9.3.2012).

## 5.1 Results

The tests were carried out in two sets. The first participant tested with version 1 of the software and used a Nokia N9 mobile phone as the mobile device. This gave me some insight into the issues with smaller devices as the Nokia N9 has a screen size of 3.9 inches. After this test I had four days before the next set and several fixes were introduced to produce version 2, which was tested using an Apple iPad. This device has a much larger screen at 9.7 inches. Although version 2 included a separate mode for landscape oriented usage only one participant noticed this and even he still preferred to use the tablet in portrait mode.

The most evident issue during the testing was the need to scroll down in the animation view. This affected 6 out of 7 participants. Eventually all discovered the hidden portions of the UI, but reaching that phase had some times dire consequences: two participants lost their created animations because they started searching for the play animation button from the other pages. Fortunately I noticed and had time to stop the third participant from doing the same mistake. One participant summarized the problem quite well by saying that the user interface looks very much like an application and not a web page, thus scrolling did not feel natural.

A frequent issue was the lack of graphics for the exclamation mark

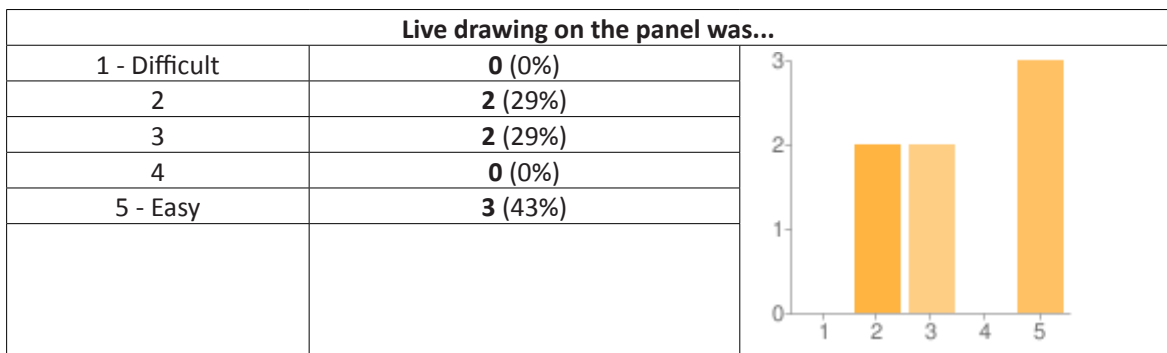
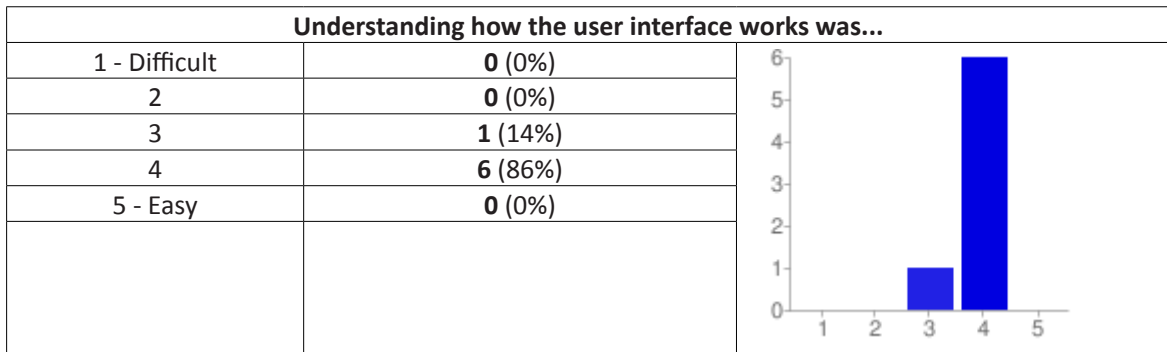
and comma from the message sending view. 4 out of 7 participants used those signs in their messages.

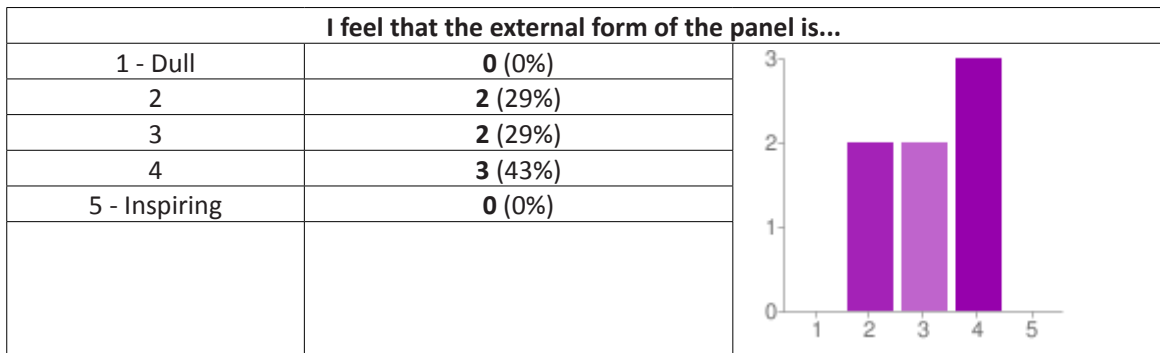
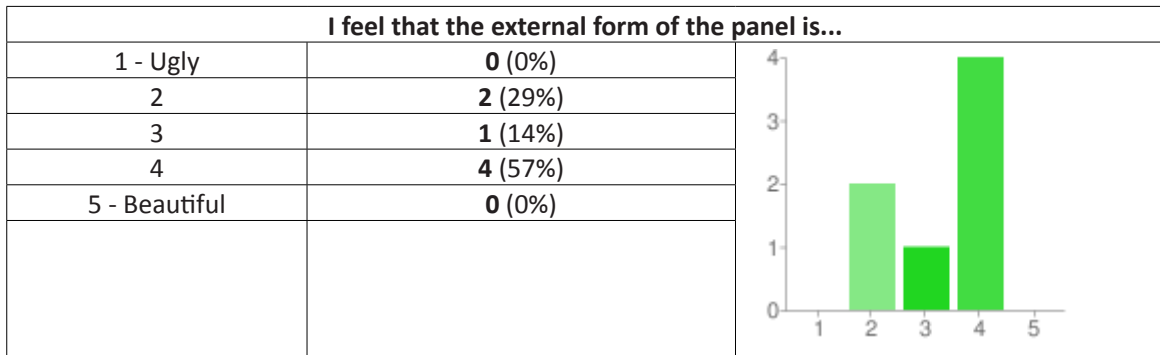
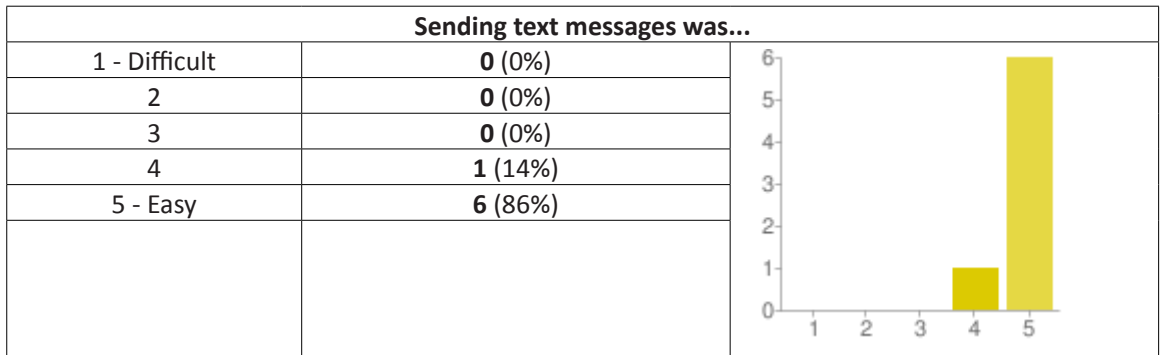
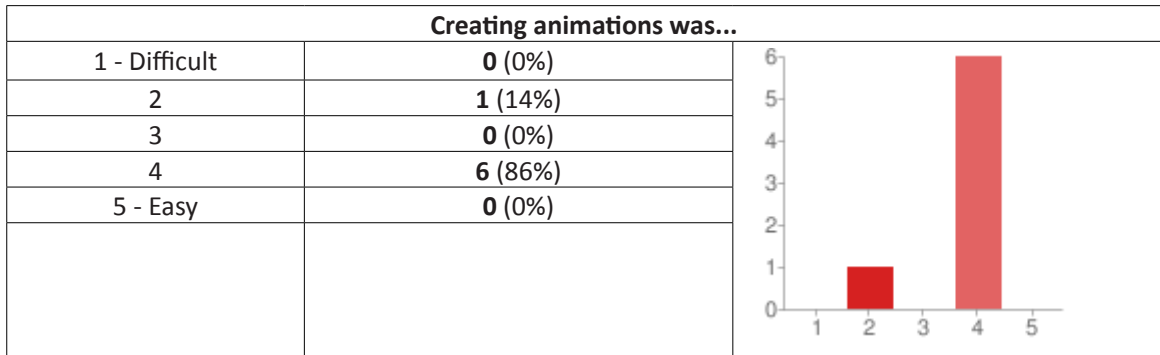
The slider introduced in the animation view for controlling the duration of each frame was troublesome for three participants who thought that it would control the time of the whole animation and thus moving it would move the animation to the next frame. One participant described this as the “Youtube-like functionality” she was used to.

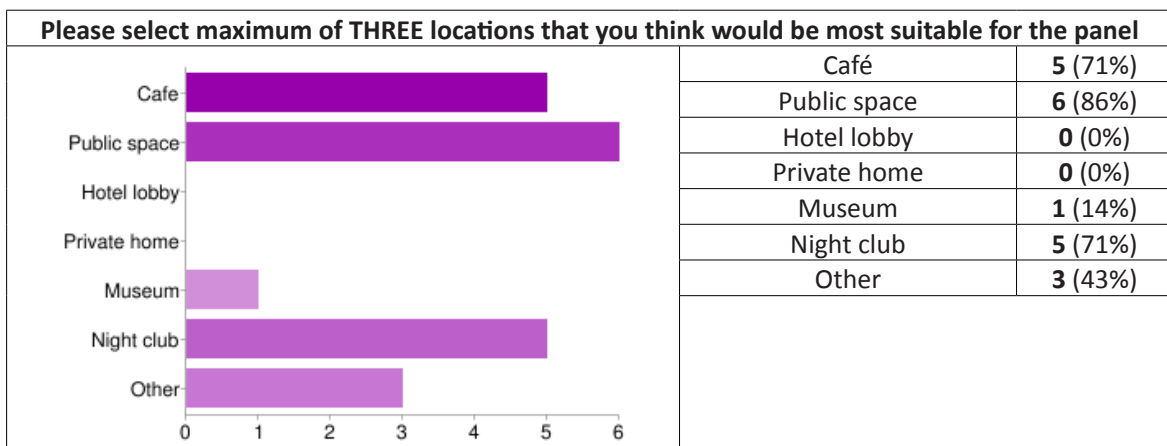
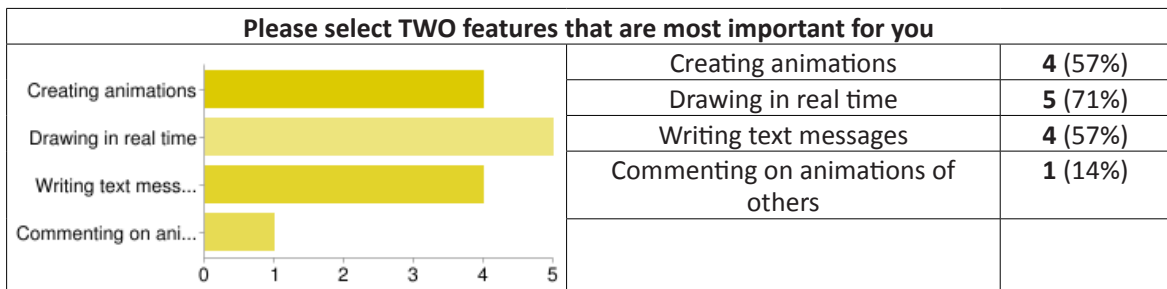
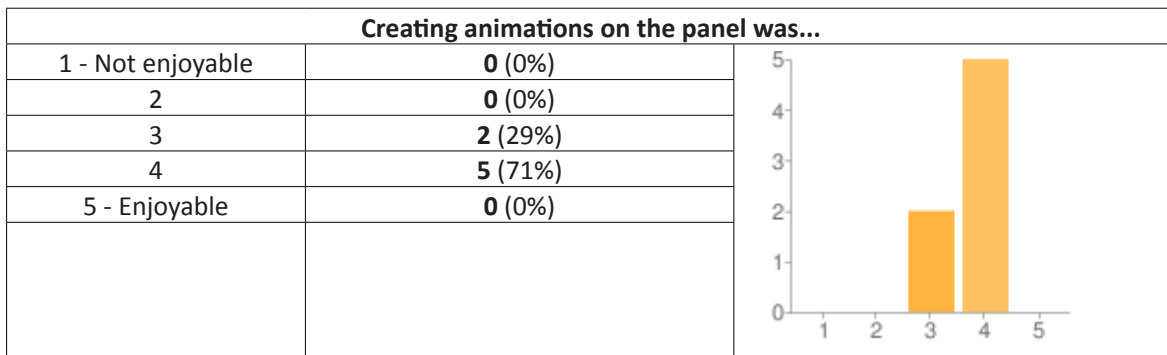
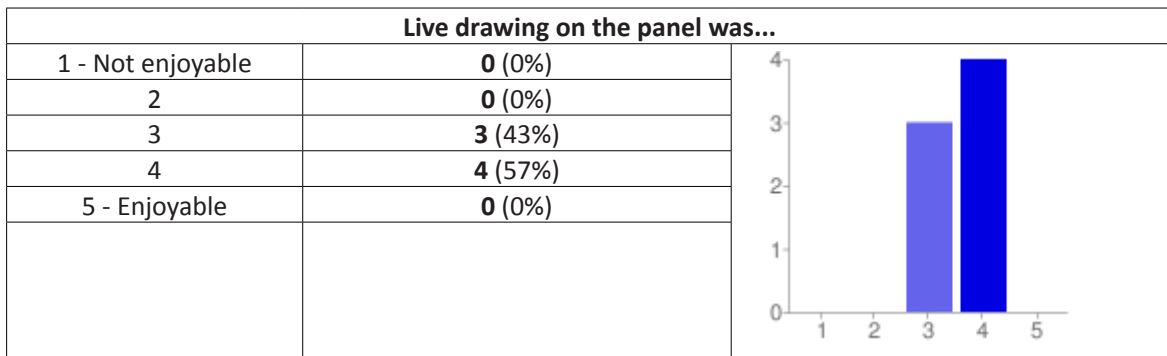
3 participants had problems playing the animation on the panel after creating it on their device. This was despite the textual guidance given to them after saving the animation. One participant was also wondering why the panel does not show what he is creating in the animation view.

### *Results from the questionnaire*

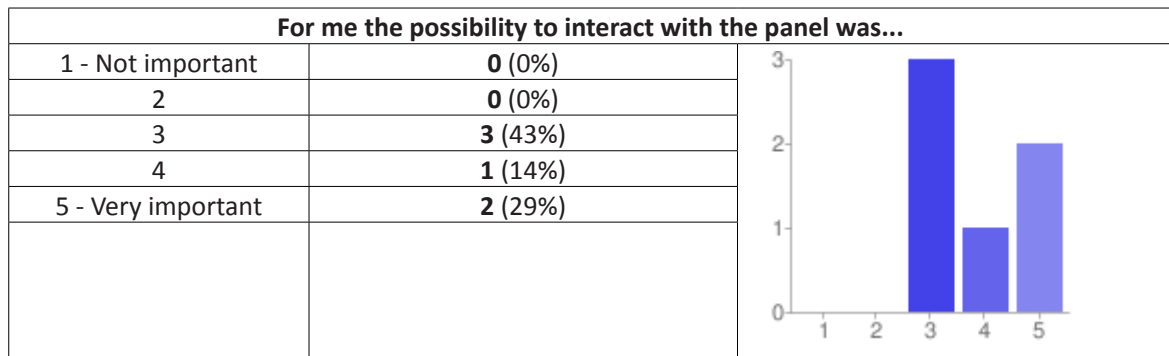
Below is a summary of the answers. The questions where the objective was to choose the best options can have percentage amounts that go above 100% as people are allowed to select more than once.











Overall it can be said that text sending was found to be easy while the animation creation and live drawing were seen as more difficult. Especially the distribution of answers on the difficulty of live drawing was a surprise. The external form of the panel did not create strong feelings. Some thought the form to be ugly, while others found it beautiful. The possibility of interaction was important to all participants and interaction was found to be enjoyable. Drawing in real-time was seen as the most important feature. Public space and Night club were seen as the two most preferable locations for placement of the panel.

The open answers to the question of missing features or other usage scenarios yielded several ideas. Features such as tweening between animation frames, looping the animations and double clicking on the drawing area to fill similar colors with the active color were expressed. Some complained about the colors on the user interface not matching the ones on the panel. Especially white color in the UI did not yield white on the panel.

Open comments revealed that three participants felt that the real potential would be exposed with several of these tiles being connected to each other making the lighting area larger. Other comments reiterated problems discovered in the usage phase and continued the list of feature suggestions with ideas such as editing previously saved animations and including visible hints that users can actually control the panel through a web-based user interface.

Overall the user testing proved out to be an invaluable portion of the design process. Much of the insight came already from watching others operate the system and many valuable points came up during the discussions. This largely contributed to the plans for version 3, which are elaborated more in the Chapter 3 and 4.



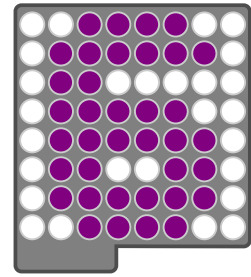
## 6 Conclusion

A two year journey ends here. The production of Dotted Landscape has been the longest solo project of my life. During the way I have learned invaluable lessons in concrete hardware design and software techniques that I probably would not have learned otherwise. For someone who is passionate about working with software, experimenting with electronics and building concrete objects, a better opportunity to combine all of these is hard to conceive.

Diving deeper into the research in public display design taught me that normal human- computer interaction theories don't suffice anymore. An extension is needed to HCI – a new paradigm to think about shared, collaborative workflows on a single device. Through the research I also found the concern many scientists and artists were expressing for the demise of our public space, continuously being eaten away by the private sector. The renegade attitude I had two years ago against big corporations taking over our urban, visual world, has been slowly replaced by genuine concern over the socio-politics of public space.

Dotted Landscape is not the ultimate solution. But it proves that change is possible. It proves that our current mobile devices are more than capable of acting as portals to more complicated interaction scenarios. The user interface proves that modern web and server technology can provide rich interaction possibilities that don't require additional software components, and the user experiments showed that interaction is viewed as important and enjoyable. We have the means to make digital public participation direct and immediate. The balance can be shifted from information push to information dialogue. The work on Dotted Landscape won't end here. The code is freely available and generic enough to be useful in any scenario where real-time collaboration is a needed feature.

It is no longer about about the technology. The question is if we – as a society – want to bring more interaction into our public spaces. Do we want to take a step towards the immediateness of the ancient Greek Agora or keep our urban visual culture mostly in the hands of those who can afford to pay for it?



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## ***Appendix 1: Production diary***

Once the production moved from pen, paper and 3D-modelling to full days spent at the wood workshop, I started keeping a quick diary to keep some kind of count of my hours. I include it here for reference in hopes that this diary will be useful to any designer planning to embark on a similar voyage. Also the diary sheds some light on how long the details in production can take. Several days were spent by just going from one shop to another to find special materials such as glue sheets and double ended screws.

**10.10.2011:** Starting day, one led sink experiment, experimenting with slot designs and ending with circular saw slit creation option. Also tested T-piece width and ended with 4mm, which was the narrowest possible. Got the model piece created and did a feasibility test at home with actual LEDs.

**11.10.2011:** Dragged milled MDF-panel to downstairs workshop from the Medialab. Experimented with the circular saw first on small piece of board to validate slit location and then did slits and gutters for wiring on the MDF-panel. Started mass-production of T- pieces. Did this by creating one long piece, which was cut into smaller 8 cm pieces with circular saw. After that I used model pieces to draw outlines on others and finalized the T- form with band saw and drilled holes to three at a time by placing the over each other and using the first as a hole guide using (1.5mm drill). The biggest problem was the use of band saw for each piece which was very slow.

**12.10.2011:** Continued creating the rest of the T-pieces. Decided to change the LED orientation on the pieces from placing the holes horizontally instead of vertically. This helps with placing the wires without shortcuts. This initially bad design decision led to the need to re-drill half of the T-pieces. By the end of the day all pieces were ready and I started constructing the bottom compartment for electronics.

**13.10.2011:** Shop day: purchased screws to attach the bottom compartment to the panel MDF.

**14.10.2011:** Screwed in the bottom compartment and visited Muovikilpi Oy to order the acrylic glass panel for the front.

**17.10.2011:** Was locked out of the workshop. Spent the day writing.

**18.10.2011:** Fetched the cut acrylic glass from Muovikilpi. Created an expansion to the bottom compartment as there was not enough room for the Fit PC. This was done by carving the compartment sides from the inside.

**19.10.2011:** Rounded the corners by first drawing the wanted form

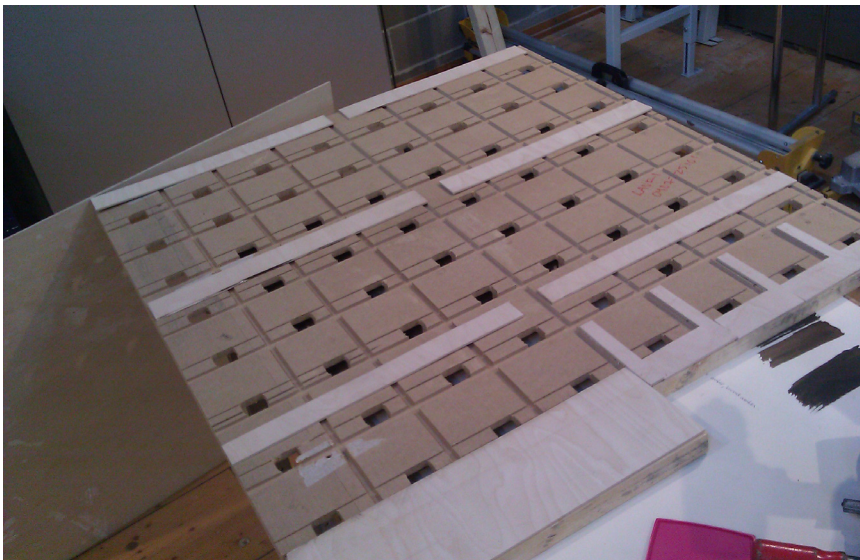


on the MDF panel and cutting it with a jig saw. After this the plywood back panel and the acrylic front were modeled by using the MDF panel as a guide. Both were cut with jigsaw. After this the back panel and front glass were attached and finishing touches were done with a sander.

I had to enlarge some of the gutters for wiring as I realized the amount of wires needed was orders of magnitude larger for some places. Also expanded the bottom compartment slightly to allow passage for wires above the Fit PC and created air holes for the air flow (another thing that was designed on the run).

**16.11.2011:** My aim was to screw pieces of plywood on the backside of the MDF to lift the back panel slightly and create more space for the ventilation and wires. However, I could not screw anything since the set design students had emptied the whole workshop of all the screwdrivers without letting the workshop master know about it.

**17.11.2011:** Brought my own screwdriver and tightened the pieces of plywood with small copper screws and glue.



**18.11.2011:** Started thinking about the veneer sides around the panel. After discussions with the workshop master we came up with two alternatives to veneering the sides. The first one was that I apply a layer of thin sheet that has a wood texture. This would be very easy since one can iron the ~0.1mm sheet around the frame and because it has a glue side ready, it sticks directly. This seals the sides and gives the impression of a wooden frame. Apparently a trick often used in cheaper furniture, like Ikea coffee tables. Option two would be to use airplane plywood. This would produce a nice thicker frame around and make

the piece more robust. The problem was that I would need to build proper pressing setup to first glue the plywood to the frame and then make it stick properly. This would've required building a counterpart for the rounded frame corners. I decided to go with the original idea. This meant I had to purchase veneer sheets and proper contact glue. Several layers of veneer would be applied around the frame to make the borders more thick. With the proper glue and thin enough veneer no additional press setup is needed.

After deciding on this I started looking for potential places to purchase the needed materials. Starkki was one option, but I decided to try Puukeskus – a company that specializes wood materials. They had a variety of veneer sheets available. I chose birch because of its popularity and rather cheap price at around 5 Euros per square meter. More exotic materials such as the darkly colored wenge were 4 times as expensive.

**28.11.2011:** I decided to paint the front side of the MDF panel. I painted the sinks white and the rest black to create contrast. 3-4 layers were used. Gluing the front panel was not as easy as I thought. The TIXO glue used with the wood veneer was not suitable as it would show through the acrylic glass in lumps. I needed to purchase glue sheets that could be applied easily on top of the panel. After searching I found a company called Taperoll. From there I was able to secure one contact glue sheet for the price of 16 euros. The size of the sheet did not match exactly the panel and for that I had to cut it into pieces. I placed the pieces in the corners of the panel to divide them evenly and after cleaning the surface, took the protective paper out from the bottom side of the glue sheet and attached it. After gluing the sheet pieces to the MDF, I cut out the LED spots with a carpet knife. Wetting the knife stops the glue from sticking while cutting. The extra cutout pieces I glued to the center piece of the frame since the overall size of the sheet did not cover the whole panel exactly.



Placing the acrylic front panel was one of the most crucial parts of the process. After removing the protecting papers from the glue sheets, I started fitting the panel on top of the MDF. This proved to be very tricky since the 300L glue in the sheets sticks instantly. Moving the panel made it worse since the thin layers of glue separated from the MDF and formed balls of goo. Once I finally got the panel to a satisfactory position, spots were apparent between the MDF and acrylic as the glue was lumped around. I went home hoping these lumps disappear in the press setup I left the panel to dry in.

**30.11.2011:** Started by attaching the back panel with 5 screw-bolts that provide the screw for the nuts and sink to the MDF (other end works like a drill). Drilling the holes beforehand was however necessary. After the front and back were attached I could start gluing veneer slips to the sides. I split the veneer leaves into half since the width I needed for the frame was just 5 cm. Attaching them happened by first applying the TIXO contact glue on one side of the veneer and then to the side to which it was going to be attached on the panel. After drying about 10 minutes the fastening happened like with Velcro. The length of the leaves was 2.5m, which proved a bit tricky to handle. Otherwise the operation was quite quick and enjoyable. A small can of glue was enough for about half of the leaves ( = 4 pieces = 8 layers).

**2.12.2011:** Finishing touches for the sides. My first instinct was to use a sander to get rid of the few extra centimeters raising above and sinking below the panel top and bottom. This would be slow, but safe. The workshop master instructed me that the best way would be to grind the sides with grinding machine. This was experimented, but there were no suitable blades to use. Unfortunate since with the correct blade this would have been a lot more faster than sanding and the edges would have been rounded automatically.

I ended up first cutting most of the extra away with a carpet knife and then sanding the rest. This was fairly straightforward, but I ran into problems on the front side, where just a slight touch with the sander would leave a visible mark on the acrylic panel which instantly lost its surface glare. A fix for this would have been to cover the panel edges with something like a few layers of masking tape. Halfway through the edge sanding I noticed that I kind of liked the blurry look of the sanded acrylic. After discussing with workshop employees and a fellow medialabber, who was also working at there at the moment, I decided that I would sand the whole panel and possibly later paint it as the glue markups made on 28th had not vanished as I hoped.



**12.12.2011:** Sanded the rest of the sides and bought contact plastic to cover the led spots during the painting. I first needed to cut 64 perfect circles with a carpet knife using a model piece made of plywood and cut with the band saw. Then I glued the circle masks to the acrylic glass. The tricky part was aligning the circles with the LED sinks.

**15.12.2011:** Bought matte black spray paint and painted the front board. Before painting I covered the sides with marking tape and newspaper.

**16.12.2011:** Another layer of spray paint was added.

**9.1.2012:** Bought stain varnish and painted the sides. The varnish dried for four hours and during that time I started building the three LED-combinations for each spot by sticking the three LEDs into the T-pieces I had cut months ago. Each LED was tested with a LED tester built out of two batteries. This ensured functioning and correct positioning of anode and cathode on each LED. The whole process combined with the painting took almost an entire day. In addition I found a piece of perforated board and decided to use that to mount the electronics. I would have to do the connections myself, but for this amount of work it would be faster than learning how to use milling system to create a custom board.

**10.1.2012:** Started electronics planning by creating components for MAX7219/MAX7221 on Upverter.com to be able to create schematics based on them. Didn't notice that somebody had already created a similar component earlier..

**11.1.2012:** Added a yet another component for the MAX7219 chip. This time the pins were placed in the physical order in which they appear (not the order used in the Arduino Playground schematics). This gives better idea of the real wire layout. Also created a component for a generic LED Matrix to include them in the design. While drawing a server error happened on Upverter and my work was not saved. Thanks to the live support in the editing view, I got in contact with "Zak" from the Upverter development team and we spent half an hour tracking the error and fixing it.

**13.1.2012:** Started the actual soldering process by inserting half of the LED T-pieces into the panel. This takes time as some of the paint applied on the front side of the MDF has dripped to the backside and is blocking the insertion. Also it seems some of the T- pieces are a few millimeters too high. Overall there is much to improve in the design, but the ones that are measured correctly can be inserted without issues. Soldered the first row of cathodes by joining the cathodes of all three LEDs in a sink.

**16.1.2012:** Soldering the cathode wires. Realized that it might be pos-



sible that the cathodes also need to be separately joined and started soldering the second row in this fashion. Joining two wires at one LED leg and doing it 24 times per each row is very time consuming. Soldering a few rows takes more than an hour. Took an approach where I cut the wires beforehand and then joined 8 wire pieces together by rolling the ends together and then putting the resulting chain in place and soldering all one after the other.

**17.1.2012:** Continuing soldering. Fitted the rest of the T-pieces into the slots. A lot of clearing with carpet knife and screwdriver was involved. In many places parts of the T- pieces had to be carved to fit them in. Albeit the design works, it might have been better to choose another approach in the beginning. I'm sure that in many places replacing LEDs means breaking the T-piece.

**18.1.2012:** Soldering the anodes. To some extent this is even more challenging as the wires for the anodes travel more distance and do a more complicated shape than the cathodes. This means that it's not feasible to build the entire row at once and then solder them quickly, but instead two wires have to be joined and then held in place with the helping hand tool while soldering.

**20.1.2012:** Soldering the anodes continued. Almost there..

**23.1.2012:** Soldering the last parts and using the glue gun to attach the wires to the MDF to make them more organized. Using the glue gun proved out to be a very good idea.

**24.1.2012:** Continued attaching the wires to the MDF with the glue gun. Started with the last pieces of wire that connect each row and column to the chip next to the Arduino. Had to come up with a quick color-marking system to later separate the wires from each other and know which wire represents which LED in which row or column. For this I used electrician's tape with three different colors. Unfortunately the tape does not stick quite well. Hopefully it'll last until I've soldered the wires into place.

**25.1.2012:** Soldered the last wires that go to the Arduino into the anodes and cathodes. Started wiring the MAX7219CNG chips by first putting them on a perforated board and then attaching them quickly with one drop of soldering tin. Connected one chip first with needed the capacitors and resistor and started joining the segments (=anodes) to the chip.

**27.1.2012:** Finished joining the anodes and cathodes to the first chip. Lifted the whole panel sideways and build a makeshift pedestal out of two pressing devices and a piece of blank to keep the panel from crashing from side to side. Removed the covers on the front panel on top of the LED sinks that were used during painting.

The first light run failed. The blue LEDs, which were the first matrix to be attached to the first chip, only flickered little. One mistake was a too small resistor, which was the result of staring to the wrong technical sheet. However this did not fix the issue entirely.

**30.1.2012:** Debugging what happened with LEDs. Another problem was detected with wrong a problem in the Arduino code that had the CLK and DIN connections reversed. This helped to fix the issue and I continued connecting the rest of the MAX chips.

**31.1.2012:** Connected a 60mm fan to the back panel to enforce air flow. Cut the electric wire coming from the Fit PC power adapter. This should provide enough 12V current to power the Arduino, LEDs, fan and PC itself. A design defect was detected as there was no separate hole for the wire to come in to the panel. One of the air outtake slits was sacrificed for this.

**1.2.2012:** Started coding the Arduino side to support three channels at once. First experiences drawing through the web interface and seeing the results on the panel.

**2.2.2012:** Created two makeshift legs for the panel to keep it vertical on a level surface. Created quickly from plywood and painted black with the remaining matte black spray.

**6.2.2012:** Finishing touches. Cleaned the clear spots on the front acrylic glass with thinner to get rid of the glue stains contact plastic. Moved the panel upstairs to the

Medialab project room. Took the first set of PR pictures, but noticed that the first row does not work perfectly. The bottom row LEDs light up always when there is a LED in that column on. This was because in the beginning, the cathodes were joined together on that row.

**8.2.2012:** Opened the back panel and re-soldered the bottom row to get rid of the unwanted flickering. Separating the cathodes fixed the issue. Now the panel is complete, but needs a few more screws to prevent the wires from bulging the back panel.

## ***Appendix 2: List of tools used during the production***

- soldering iron
- helping hand for soldering
- solder pump to remove soldered joints
- peak pliers
- multi-meter
- cable peeling pliers
- cable cutters
- screwdriver (various sizes)
- carpet knife
- measuring tape
- circular saw
- band sawing machine
- planer
- jigsaw
- sanding machine
- sanding paper
- drilling machine (battery powered)
- milling machine
- paint brush (various sizes)
- pressing devices (various sizes)

### ***Appendix 3: List of raw materials used***

- MDF (milled panel core)
- Birch veneer (panel sides)
- White paint (LED sinks)
- Gray paint (LED sinks)
- Black paint (front side outside of LED sinks)
- Black spray paint (front glass outside of LED sinks)
- Stain varnish – mahogany color (veneer sides)
- TIXO contact glue (for the veneer sides)
- 3M glue sheets (gluing the front acrylic panel to the MDF)
- acrylic panel – milky white 4mm (front panel)
- plywood (T-pieces, backboard, structures inside)
- wood board (edges for the computer section in the bottom part)

### ***Appendix 4: List of electronics and computer parts***

- 192 10mm LEDS – red, green and blue
- 3 Maxim MAX7219CNG microchips (led drivers)
- Arduino Uno (microcontroller)
- FIT PC2 (embedded Linux computer)
- resistors, capacitors, wire (various sizes)
- 80mm computer fan (cooling the electronics)

Overall price for the production is around 750 €, out of which about 500 € covers the Fit Pc. Price for the MDF and wood material is not included.





